A Land Suitability Assessment for Sugarcane Cultivation in Angola - Bioenergy Implications

By

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Abstract

Bioenergy is a source of clean, renewable energy and is seen as a promising endeavor in mitigating and abating climate change. Its use brings various social, environmental and economic benefits and particularly for Africa, bioenergy offers opportunities to improve energy security and reduce dependence on foreign exchange earnings, which would bring Africa's poor closer to a secure energy future. A predominant source of bioenergy supply is in the form of specific bioenergy crops, of which sugarcane, sweet sorghum and maize are examples. This study focused on the cultivation of sugarcane for bioenergy purposes and aimed to delimit areas suitable for cane cultivation in Angola. Sugarcane was selected as the bioenergy feedstock due to its variety of by-products which includes bioethanol for gasoline blending and bagasse for electricity cogeneration. Due to its high agricultural productivity, sugarcane was the favoured bioenergy feedstock. Angola was selected as the study area due to its large areas of non-forest agricultural land which affords significant capacity for bioenergy production.

Geographic Information Systems was used as the key tool in identifying areas suitable for sugarcane cultivation. As this study serves to promote social, economic and environmental sustainability, areas which are currently under food production, protected areas as well as areas of biological significance were filtered out from the study area. The areas identified following this step was an indication of areas which are potentially available and suitable to grow sugarcane without environmental constraints. However, in order to determine the viability of establishing sugarcane farms at the areas identified, a further selection process was conducted, considering the non-biophysical factors influencing sugarcane production. These included proximity to roads, transport infrastructure, areas greater than 10 000 hectares and population data. This inspection resulted in three areas being selected as potentially suitable for sugarcane cultivation. The selected areas cover 0.9% of the study area, covering 10 614 km^2 of land. Although this may be a small percentage of the study area, potentially suitable areas are concentrated in eight provinces in the south, central and northern regions. In addition, as this study focussed on irrigated agriculture, slope and proximity to rivers were analysed as these are the two main considerations influencing irrigation at the selected areas. Results indicate that Angola's irrigation potential is largely unexploited and due to the vast network of rivers flowing through the country, irrigated agriculture appears encouraging. An analysis of Angola's transport infrastructure highlights concern over the poor condition of roads which may be an impediment in establishing sugarcane farms at the suggested areas. However, processing capacity at each of the selected areas appears encouraging as each of the selected areas has the potential to house a minimum of three mills in its manufacturing phase. Furthermore, the large population base at each of the selected areas, a low HIV prevalence rate and an unemployment level of 50%, indicates a great likelihood of available workforce for each of the selected areas. These findings suggest that Angola has a considerable capacity for agricultural expansion, especially into bioenergy which is a promising endeavour in uplifting the social welfare of its citizens as well as a sound financial and development option contributing to the sustainable development of the country.

Several recommendations have emanated from the results obtained in the study of which includes the encouragement of establishing international cooperations between Angola, the North and Brazil in order to bring scientific, technical and agronomic expertise into the country for bioenergy development.

PREFACE

The work described in this dissertation was carried out in the School of Environmental Sciences, University of KwaZulu-Natal, Durban, from February 2007 to December 2007, under the supervision of Dr. Helen Kerr Watson.

This study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any other University. Where use has been made of the work of others, it has been duly acknowledged in the text.

Leena S Ackbar

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Chapter 1

Introduction

1.1 Introduction

The following sections serve to provide an introduction to the study by outlining the motivation for the study, choice of biomass feedstock and the study area. The chapter also includes aims and objectives of the study and provides an outline of the structure of the thesis.

1.2. Motivation for study

Environmental awareness is on the increase, framed by threats of climate change and its multitude of adverse impacts upon Planet Earth. Contemporary environmental issues are therefore often related to the phenomenon of Global warming, related to emissions of greenhouse gases (GHG), mainly carbon dioxide (CO_2) produced from the burning of fossil fuels (Kartha *et al*., 2005; de Vries *et al*., 2007; Demirbas and Demirbas, 2007; Mathews, 2007a; Mathews. 2007b). Logically, the most obvious endeavor to curb global warming would be to reduce GHG and the burning of fossil fuels, however, as obvious as this may seem, growing demand from the energy, transport and industrial sector places heavy constraints on such options. The transport sector is the major consumer of petroleum fuels and is likely to suffer badly as a result of increasing petroleum prices, the finite petroleum reserves and the increasing number of petroleum-based vehicles worldwide (Demirbas, 2007).

However, amidst Earth's finite systems and finite resources, there exist infinite possibilities to assist in the transition to a more environmentally friendly future and at the same time meeting growing energy demands. As a result, much attention has been directed towards renewable energy resources, more specifically the use of biomass, as an alternative to non-renewable fossil fuels, which is fast approaching its life span. Biomass energy or bioenergy is one potential use of biomass, which is the use of plant and other organic matter (converted by the process of photosynthesis), to provide energy services such as heat, light and motive power (Kartha *et al*., 2005). Plant biomass can be used to absorb carbon dioxide released during the burning of fossil fuels, or it can be transformed into a modern form of energy. In this form, modern bioenergy can be used to produce energy carriers such as electricity, liquid and gaseous fuels (Hall and House, 1995).

In addition to its ability to mitigate climate change, several reasons account for the gaining popularity of bioenergy. As outlined by de Vries *et al*., (2007), the risk of energy supply insecurity and the prospect of non-renewable resource depletion such as oil and gas, foster concerns which can be subdued by renewable energy potentials. Although several new fossil fuel reserves have recently been found in Africa, access to the reserves is often correlated with conflict. Thus, coupled with this, the economic viability and various social and environmental benefits of bioenergy, make it one of the main renewable energy resources (Hall and House, 1995).

Biofuels, which is a form of modern bioenergy, is promoted as being a viable substitute to fossil fuels, such as petroleum fuels. Its main quest would be to reduce carbon and sulphur emissions, thereby reducing atmospheric carbon dioxide levels. Its potential for rural development, energy security, foreign exchange savings and socio-economic issues related to the rural sector, gives further incentive for its use (Cadenas and Carbezudo, 1998).

According to Cadenas and Carbezudo (1998), the are four broad categories of potential biomass feedstocks: (1) organic or industrial wastes; (2) agricultural crop residues and wastes including manure, straw, bagasse and forestry waste, (3) existing uncultivated vegetation and (4) energy plantations, which involve energy crops such as sugarcane, maize or sweet sorghum. Sugarcane in particular has been noted as an efficient biomass feedstock, both for its agricultural residues which are produced in abundance, and its use as a dedicated energy crop. For example, ethanol is produced from sugarcane which can be used as a gasoline blend or substitute (Blume, 1985). Interestingly, ethanol was already considered as an acceptable automotive fuel as the first FORD automobile made during 1908-1926 could run on either petrol or ethanol (Bucheit, 2002; Kovarik, 2003; Johnson and Rosillo-Calle, 2007). However, when crude oil began being cheaply extracted, it was more profitable for cars to run on oil rather than ethanol. But soon this reasoning was reversed, sparked by rising oil prices in the 1970s. Interest was then directed towards alternate sources of fuel and as a result bioethanol gained new importance (Blume, 1985).

In addition to sugarcane, ethanol can be produced from other sugar crops, including sweet sorghum (*Sorghum spp,*), from starchy crops such as cassava (*Manibot esculenta*), corn (*Zea Mays* L.), potato (*Solanum tuberosum*) and babassu palm (*Orbingnya martiana* MART.) and from celluloses (Blume, 1985). However, for the purpose of this study, sugarcane has been selected as the preferred biomass feedstock for the production of energy.

1.3. Motivation for choice of biomass feedstock - Sugarcane

The variety of by-products produced from sugarcane makes it one of the most valuable agricultural resources, and its use as an energy source categorises it as an efficient bioenergy crop (Blume, 1985). Among its variety of uses, sugarcane is an efficient producer of ethanol using cane juice, bagasse and molasses, and amongst tropical energy crops, ranks first in terms of agricultural productivity and yield of ethanol per hectare sugarcane (Blume, 1985). It also has the most positive energy balance, as bagasse, the fibrous residue of cane left after the extraction of juice, can profitably be used as fuel in the industrial phase of ethanol production, whilst additional fuel is required when processing cassava (Blume, 1985).

Additionally, bagasse, can be used for electricity cogeneration, as in the case of Mauritius (Gabra and Kjellström, 1995; Deepchand, 2001). In 1988, the sugar industry in the country exported electricity to the public grid accounting for 19% of the island’s requirements, with 13% of this originating from bagasse (Deepchand, 2001). Ten years later, in 1998, close to 25% of the country’s electricity was generated from the sugar industry (Deepchand, 2001). This study will therefore focus on sugarcane cultivation for bioenergy purposes, addressing biofuels, electricity cogeneration and a variety of other high-value end products, which will be discussed in later chapters.

The production of bioenergy from sugarcane has been greatly exploited in several countries, but more so in Brazil which is heralded as the greatest producer of bioethanol from sugarcane and electricity cogeneration from bagasse (Blume, 1985; Mathews, 2007b). Its National Alcohol Program (PROÁCOOL) established in 1975 gave new importance to the sugar industry. Coupled with its National Sugarcane Improvement Program (PLANALSUCAR) it took advantage of the low price of sugar in the world market as an incentive to start its alcohol program. By June 1981, its success was eminent, reflected by the 375 000 automobiles using ethanol as fuel, however, that was only the beginning. Currently Brazil produces nearly 20 billion litres of ethanol per year and the number of flex-fuel vehicles which can run on both ethanol and gasoline represents 73% of new cars sold in 2006 (Mathews, 2007b; Xavier, 2007). But what about the rest of the world? In order to achieve the desired 5% reduction in GHG emissions by 2012 as stipulated by the Kyoto Protocol, a global initiative most definitely has to be sought.

According to Mathews (2007b), currently the world consumes petro-oil at the rate of approximately 84 million barrels per day, and the OECD is responsible for consuming half of this oil, of which 58 percent is used for transport. This vast amount of non-renewable energy is what eventually needs to be replaced by alternate fuels. But do these countries, often termed the ‘North’, have the capacity to meet such demands? According to Claude Mandil, the head of the International Energy Agency, and sister organisation to the OECD, the North faces the problem of land availability, and the disturbances to the markets for corn and grain (the principle feedstocks in the US) and to sugarbeet, the principal feedstock in the EU, would be far too great (Mathews, 2007b). In other words, there is an utter infeasibility of the North to produce such a biofuel output (Mathews, 2007b). As a result, the OECD has to direct its efforts to finding solutions in the South, more specifically developing countries which has untapped bioenergy potential.

In order to meet the energy demands of the OECD, the South would have to replicate what Brazil currently achieves 18 times over, within the next decade (Mathews, 2007b).

This would require the South to have 72 million hectares of land placed under biofuel cultivation, a land area size equivalent to that of Chile. But is this land area available?

According to the Food and Agricultural Organisation's (FAO) Terrastat database (2003), in just the African countries that signed up for the 'Green OPEC'[1], there are 379 million hectares of potentially arable land available, of which only 43 million are utilised. In addition, if the whole of sub-Saharan Africa, South Asia, Southeast Asia, Latin and Central America are added, then over 2 billion hectares of potentially arable land is available, which is well in excess of the calculated capacity of the OECD (Mathews, 2007b). Thus, these figures have directed significant attention towards developing countries, such as Africa, in realising a transition towards global use of alternate energy sources.

1.4. Motivation for study area - Angola

Studies are now aimed at finding suitable areas in arid and semi-arid regions of Africa and Latin/South America for biomass production for energy. This study forms part of one such study carried out through the Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semi-arid Ecosystems (COMPETE). It is a South-South-European Union cooperation which focuses on Africa (COMPETE, 2005). For this study, Angola has been selected as the study area upon which a land suitability assessment will conducted.

Generally, land suitability studies have tended to exclude countries facing political instability such as Angola and the Democratic Republic of Congo, and have thus, focussed on areas where bioenergy crop cultivation appears most encouraging (Watson and Garland, 2004; Baijnath, 2005). One such study is a land suitability assessment by Baijnath (2005) for sugarcane cultivation in Malawi, Mozambique, Tanzania and

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[1] An organisation which unites 15 non-oil producing African countries, aimed at making African countries less dependent on oil by replacing it with biofuels. The organisation is dubbed the 'Pays Africans Non-Producteurs de Pétrole' (PANPP) (http://biopact.com/2007/05/senegal-and-brazil-sign-biofuel.html). A list of these countries are given in 'A closer look at Africa's 'Green OPEC' at http://biopact.com/2006/08/closer-look-at-africas-green-opec.html

Zambia. The study analysed these four Southern African countries in terms of land available to delimit suitable areas for sugarcane cultivation. The political situation facing countries like Angola and the Democratic Republic of Congo discouraged investigations into delimiting suitable areas for sugarcane cultivation, and thus, were not considered as a study area. However, as would be described in this section, there are several reasons supporting the expansion of bioenergy crop cultivation in Angola, making it one of the countries which make Africa's future sustainable bioenergy production so large (population (Van Den Berg and Rademakers, 2007).

Angola was delimited as the study area due to the large areas of non-forest agricultural land available for the cultivation of energy crops even after meeting its needs for food, fiber, feed and fuel wood for its growing population (Van Den Berg and Rademakers, 2007). Angola has a total of 88 million hectares of suitable land for agriculture, and currently only 3.6 million hectares are used for crop growth (Van Den Berg and Rademakers, 2007). By the year 2050, its is projected that Angola would have enough land available for the sustainable production of roughly 5.945 Ej of net energy per year, after meeting the requirements of its growing population (Van Den Berg and Rademakers, 2007). Angola is therefore suggested to be the next 'biofuel superpower' (Van Den Berg and Rademakers, 2007). As it is estimated that only 15% of Angola's population have access to electric power (www.esri-africa.com), the potential of using electricity cogenerated from bagasse may serve as an incentive for bioenergy implementation. Furthermore, as Angola is in the process of rebuilding its infrastructure that was damaged by the 27 years of civil war, bioenergy has the potential to be a sound financial and development option contributing to the sustainable development of the country.

Specifically, the Angolan government sees renewable, clean energy as a promising endeavour to address the basic development needs of low-income populations. In 2001, at the Commission on Sustainable Development, Angola's Minister of Energy, Luis Filipe da Silva said that in developing countries poverty was mainly concentrated in rural areas where energy is predominantly provided by firewood and other forms of biomass, which is also the case for Angola. The main source of energy in rural areas are conventional hydro and fossil fuels which are environmentally harmful and a strong limiting factor in rural areas (Commission on Sustainable Development, 2001). Therefore, improving access to cleaner forms of energy, such as bioenergy, becomes a critical endeavour in freeing the poor, especially women from subsistence farming (Commission on Sustainable Development, 2001). The minister further added that in Angola, there is undoubtedly a need and demand for energy services, and especially post-civil war when the country's economy is growing, energy demands are projected to dramatically increase. Angola's socio-economic and energy situation emphasises the necessity of introducing non-polluting energy sources. By introducing bioenergy, in addition to energy security, it would provide access to energy services without adverse health and environmental impacts and would provide income-generating activities for the poor, which could alleviate poverty. Therefore, the introduction of bioenergy, will facilitate the journey to sustainable development by improving environmental conditions, the social welfare and standard of living in the country.

In addition, as 85% of Angola's labour force is involved in agriculture, it would seem plausible to begin an economic transformation and social upliftment in this very sector, facilitated by bioenergy crop cultivation.

1.5. Aim of the study

The aim of this study is to delimit areas suitable for sugarcane cultivation for bioenergy purposes in the sub-Saharan country Angola.

1.6. Objectives of the study

In order to meet the proposed aim, the following objectives have been outlined:

1. To delimit protected areas and areas currently used for food production which will be excluded from any further analysis
2. Use of a Digital Elevation Model to identify slopes posing a constraint to sugarcane cultivation

In addition to the objectives stated above, for the results to be of significant use to land use planning, a non-biophysical component will be addressed in this study. Specifically, the areas identified by following objectives 1 and 2 will be analysed to determine practical implications and viability of establishing a sugarcane farm at the selected areas. This involves the consideration of infrastructure requirements such as roads and railroads. Population data is also included in these considerations. The non-biophysical considerations constitute a broader discussion of each of the selected areas in terms of the surrounding social and physical contexts. Demographic considerations include HIV/AIDS prevalence rates and level of education.

The non-biophysical considerations are an essential component to this study as an area may be biologically and geographically suitable for sugarcane production, but it may not have the necessary infrastructure and labour support for its implementation.

Furthermore, the study addressed irrigated agriculture and thus, assesses distances to water sources and slope.

Therefore a third and fourth objective is added to this study:

3. Critically analyse and determine viability of bioenergy crop production in the identified areas in the framework of non-biophysical conditions
4. Calculate distance from agricultural area to water source and slope (%) from agricultural area to water source

1.7. Structure of the thesis

The thesis is divided into 7 chapters. Chapter 1 provides an introduction to the study outlining aims and objectives. The background to the study is covered in Chapters 2 and 3, with Chapter 2 providing an overview on biomass and biomass energy as well as bioenergy implications for Africa. Chapter 3 highlights the ecological requirements for successful sugarcane cultivation, concluding on an overview of the infrastructural and social considerations in sugarcane production. The study area is described in Chapter 4, paying attention to its location, geography and the state of agriculture in the country.

Chapter 5 provides an overview of the methodology undertaken in the study. The theoretical approach, data sources, and a detailed description of the analysis are provided in this chapter. The results of the study are presented in Chapter 6. A discussion of the results obtained is also included in this chapter. The thesis culminates with Chapter 7 which provides a conclusion to the study also including recommendations that emanated from the study.

Chapter 2
Background on Biomass and Biomass Energy

2.1. Introduction

Energy derived from biomass has been used for thousands of years ever since people used wood for fire, to cook food or to keep warm (Demirbas and Demirbas, 2007). Traditionally, wood has been the largest biomass resource, which is still reflected in many countries of the developing world. It is estimated that almost half of the energy used in the African continent is in the form of fuelwood (Demirbas and Demirbas, 2007). Furthermore, in developing countries, biomass is a major energy source, accounting for more than 90% of the total rural energy supplies (Hall and House, 1995; Demirbas and Demirbas, 2007). As these areas have no access to modern forms of energy, biomass resources becomes the most appropriate means to supply the basic energy requirements for cooking and heating in rural households (Demirbas and Demirbas, 2007). However, biomass consumed in these forms, constitute the traditional use of bioenergy, bearing both social and environmental costs. Implications such as indoor and outdoor pollution, physical and mental health problems and forest and soil degradation are some of the problems associated with the traditional use of biomass, particularly observed in the developing regions of the world (Barnes, 2006). These costs are a heavy price to pay, especially when continual use and its implications are projected into the future. The World Health Organisation (WHO) ranks indoor air pollution, a result of burning unrefined biomass, as the 8th top health risk worldwide, killing 1.6 million infants, young children and women each year (Barnes, 2006; Kammen, 2006).

Traditional biomass usage in its unprocessed form is characterised by low efficiency and in conjunction with the various associated social, health and environmental insults, much attention has been directed to new technological innovations in bioenergy. As such, cleaner, high efficiency, renewable energy sources has gained political importance, heralded as being the key facilitator for economic and social development in developing countries. This chapter will provide a background on biomass and bioenergy, delving into its variety of uses and implications within the energy sector. Departing from a global focus, bioenergy will be analysed in the developing world context, outlining the importance of collaboration between the North and South in current global energy demands.

2.2. Biomass and biomass energy

Biomass energy refers to the energy that can be derived from biomass. Biomass, in its simplest form is any organic material of biological origin that has stored sunlight in the form of chemical energy (photosynthetically derived) (Demirbas and Demirbas, 2007). Most of the standing biomass is in the form of woody forest materials, with most land biomass being composed mainly of cellulose, hemicellulose and lignin (Klass, 2004). Essentially, all biomass is produced by green plants by the process of photosynthesis, and predominant biomass sources include wood, wood waste, straw, manure and sugarcane (Hall *et al.*, 1993). Secondary and tertiary forms include many forest and farm commodities and various byproducts of agricultural, forestry, manufacturing and day-to-day living in a developed urban society (Alexander, 1985).

Biomass has several uses which can often be summarised in terms of the 4Fs: Food, Feed, Fibre and Fuel (Johnson and Rosillo-Calle, 2007). Within this broad categorisation, some of its uses include: a source of material for shelter, role in nutrient cycles and functional synergies, ecosystem functions and integrity, and provision of local business opportunities. However, its use as a renewable energy source makes it the focus of contemporary energy discussions and warrants it greater global attention. As an energy source, biomass can be used by either burning it directly or converting into liquid, solid or gaseous fuels using conversion technologies such as fermentation, bacterial digestion and gasification, respectively (Hall and House, 1995). Globally, biomass accounts for 11% of total primary energy consumption (Figure 2.1.) and in developing countries it is the number one energy source (Johnson and Rosillo-Calle, 2007).

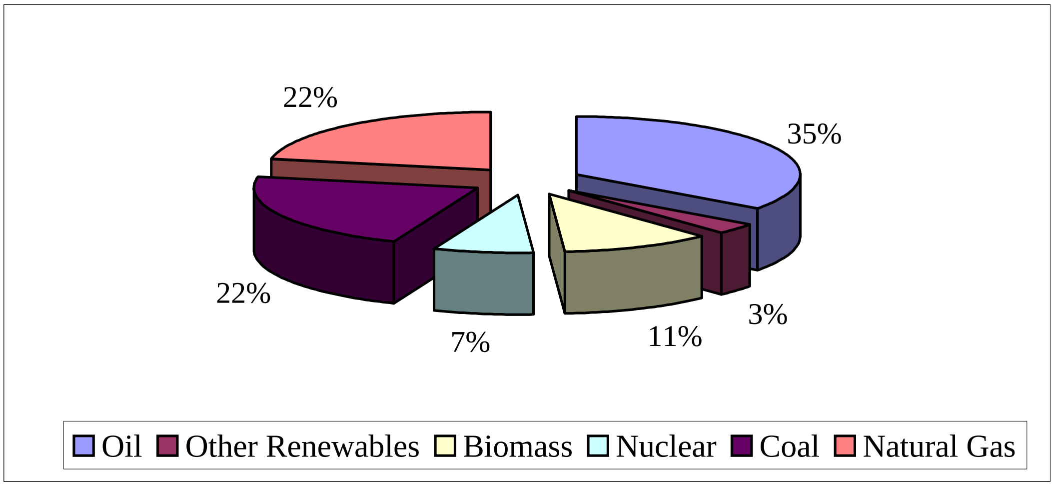

Figure 2.1. Global primary energy consumption (Johnson and Rosillo-Calle, 2007)

However, in developing countries it is often the traditional use of biomass that dominates, such as the burning of wood, agricultural residues and dung. Specifically, an overwhelming 85% of biomass energy is consumed as solid fuels in traditional uses for cooking, heating and lighting, which is a very inefficient use of biomass, utilising only 5-15% of the actual energy (Hall and House, 1995; Johnson and Rosillo-Calle, 2007). In sub-Saharan Africa, dependence on traditional biomass accounts for over 61% of primary energy consumption (Figure 2.2.) (Johnson and Rosillo-Calle, 2007).

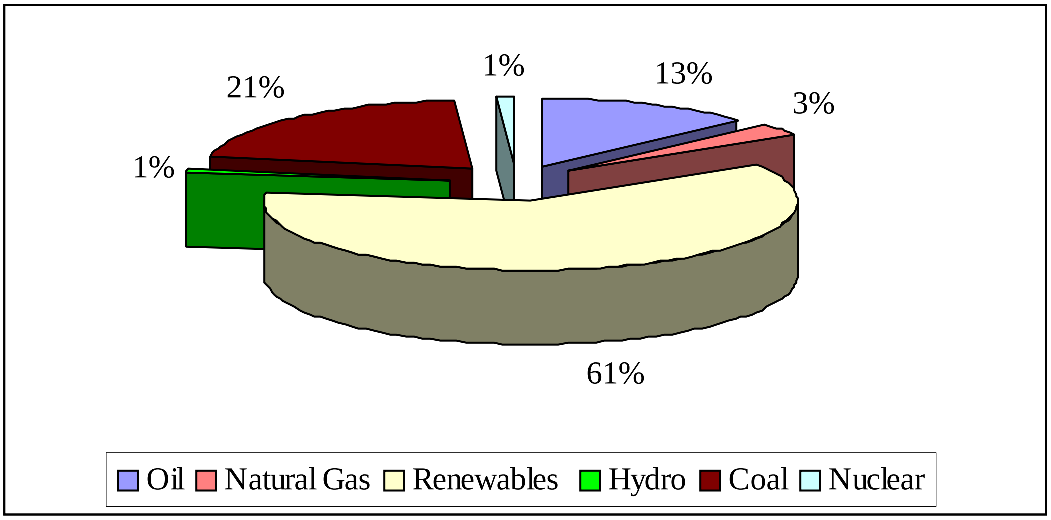

Figure 2.2. Primary energy consumption in sub-Saharan Africa (Johnson and Rosillo-Calle, 2007)

More than 2 billion people lack access to modern energy services and as a result rely heavily on traditional biomass fuels (UNDP, 2004). This dependence fosters various social, health and environmental implications, and can be considered as a catalyst for the socio-economic situation which many individuals in developing countries have to endure. Basic services such as health and education require electricity and reliable energy, which means that those 2 billion people who lack access to modern energy will also be deprived of such services. Furthermore, the possibility for commercial enterprise which requires modern energy, is drastically reduced due to a lack of lighting, labour-saving devices and telecommunications, further adding to the dire socio-economic situation. The situation is further exacerbated due to dependence on traditional biomass systems which has other implications for rural livelihood, often associated with the task of collecting biomass for consumption. Specifically, women and children spend arduous hours every day trekking over large distances to gather wood for fuel, time which could rather be used for creating income generating opportunities and educating children (Goldemberg *et al.*, 2004). Shifting from traditional to modern bioenergy therefore becomes an essential move to aid social and economic upliftment.

2.3. The transition from traditional to modern bioenergy

According to Hall and House (1995), if biomass is used more efficiently, it can supply a considerable range and diversity of fuels at both small and large scales and can form part of a matrix of fuel sources, which would offer increased flexibility of fuel supply and energy security. This could further reduce the dependency on oil imports, keeping expenditure within the local economy, which in addition can free land that was previously needed to grow crops for foreign currency earnings. Land could then be used for bioenergy plantations, which would play a role in local decentralisation, assisting communities to remain self-sufficient in energy, thereby promoting sustainable development. Furthermore, as growing biomass is labour intensive, it brings with it opportunities of job creation together with providing energy to promote other rural industries. Reflecting upon these numerous benefits, the shift to modern bioenergy for developing countries would then be an attractive transition.

Globally, modern bioenergy can also deliver a variety of benefits. It provides higher quality energy services that are more versatile and efficient than traditional bioenergy, delivering well-controlled energy services (Leach and Johnson, 1999). Like all other renewables, modern bioenergy can make a valuable contribution to climate mitigation and in the overall transition towards sustainable energy sources. Modern bioenergy is suggested to have two main advantages over other renewables, which makes it the favoured choice in the strive towards a cleaner, environmentally friendly future. First, biomass is stored energy or 'available energy on demand' which can be drawn on at any time, unlike other renewables such as daily or seasonal intermittent solar, wind and hydro sources "whose contributions are constrained by the high costs of energy storage" (Kartha *et al*., 2005; Johnson and Rosillo-Calle, 2007). Second, biomass also has the capacity to produce all forms of energy carriers for modern economies such as electricity, gas, liquid fuels and heat, whereas energy from solar, wind, wave and hydro are limited to electricity and in some cases heat (Johnson and Rosillo-Calle, 2007). It can also serve similar ends by replacing traditional cooking fuels with cleaner, smokeless and efficient liquid and gas alternatives based on renewables rather than fossil fuels (Kartha *et al*., 2005)

Among the multitude of advantages and opportunities associated with modern bioenegy, undoubtedly its potential in being an alternate to fossil energy and mitigating rising CO_2 levels accounts for the enthusiasm observed worldwide.

2.3.1. The Role of Modern Bioenergy in mitigating Climate Change

Two global environmental initiatives were responsible for stimulating interest in renewables (Karekezi, 2002). First, the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil in 1992 which resulted in Agenda 21, a document which sought to operationalise the concept of sustainable development. Second, the conference also provided the venue for the signing of the United Nations Framework Convention on Climate Change (UNFCCC), and within both initiatives, renewables were perceived as an important option for mitigating and abating GHG emissions (Socolow, 1992; cited in Karekezi, 2002, p1059). But, the alarm bells of climate change are ringing louder in 2007, with a dawning awareness that Planet Earth faces a crisis of unprecedented magnitude (Mathews, 2007a). There seems to be a consensus that there is at most 10 to 20 years within which major changes have to be made to reduce GHG to avoid a man-made catastrophe (Mathews, 2007a). Furthermore, the Kyoto Protocol, adopted in 1997 at the third Conference of Parties (COP 3), shares the principles, objectives and institutions of UNFCCC, has set legally-binding targets for developed countries to limit or reduce GHG by at least 5% from 1990 levels in the 2008-2012 commitment period (Atkinson, n.d.).

So what is the role of modern bioenergy in all of this? By identifying energy use as the main source of GHG emissions, driven by increasing fossil fuel demands, the role of bioenergy in mitigating climate change becomes apparent. First, bioenergy is a source of clean, renewable energy which can be used as an alternate to fossil fuels (Blume, 1985; Hall and House, 1995; Demirbas and Demirbas, 2007; Mathews, 2007a; Mathews, 2007b). Combustion of biomass as a fuel source results in no net release of carbon emissions and when used instead of fossil fuels, carbon emissions from the displaced fossil fuels are avoided as well as other associated pollutants like sulphur (Hall and House, 1995). Second, there is undoubtedly an interlinking connection that forms between modern bioenergy, fossil fuels and climate mitigation. Replacing fossil fuels with forms of modern bioenergy such as biomass-derived fuels (e.g. bioethanol, biodiesel), will not only facilitate a transition to a low carbon energy future but will also be key in meeting growing energy demands owing to its significant environmental and economic potential. The majority of the world’s energy needs are supplied by petrochemical sources, coal and natural gases, and with the exception of hydroelectricity and nuclear fusion energy, all of these resources are finite (Demirbas and Demirbas, 2007). Furthermore, increasing pressure is placed upon finding alternate resources, preferably renewable, as at current usage rates existing non-renewable resources will be consumed shortly (Srivastava and Prasad, 2000). The rapid decrease in finite stocks of fossil energy, peaking oil prices, growing dependence on fossil fuels, especially the transport sector and the accumulation of associated GHG during combustion, has therefore stimulated much interest in biomass-derived fuels. Overall, because modern bioenergy is a renewable resource, has the capacity to reduce levels of GHG, and can be used as an alternate to fossil fuels, it has fundamental potential in meeting global energy demands coupled with opportunities for economic and environmental development.

2.4. Forms of Modern Bioenergy Use

Modern bioenergy boasts a diversity of uses and applications, both at large and small scales. At large scales, biomass utilisation encompasses direct combustion for process heat, ethanol production, gasification, heat cogeneration, biogas production and briquetting. However, the best-known large-scale biomass energy systems are electricity co-generation and the production of ethanol as a substitute for petroleum (Marrison and Larson, 1996). At small scales, the importance of bioenergy systems lies in the large number of end users that these systems serves (Karekezi, 2002). At this level, importance lies in biofuelled cookstoves which meet the bulk of cooking, heating and lighting needs of most rural households in Africa as well as charcoal and biogas (Karekezi, 2002). Its use can further be extended to the industrial sector with environmental and economic benefits, and can be scaled down within individual households providing social and health upliftment. This section aims to provide an overview of the most common and widely used forms of modern bioenergy, outlining the associated social, environmental and economic benefits that its use can deliver.

2.4.1. Biofuels

Biofuels refer to liquid or gaseous fuels that are predominantly or exclusively produced from biomass (Demirbas, 2007; Demirbas and Demirbas, 2007). Some of these fuels can be directed to the transport sector, such as bioethanol or biodiesel as a substitute for petroleum fuels, whereas bio-oils can be used to generate heat, power and/or used in the production of chemicals (Demirbas and Demirbas, 2007). Biofuels are considered as offering many benefits which include sustainability, reduction in GHG emissions, regional development, improvements in social structure and agriculture as well security of energy supply (Demirbas and Demirbas, 2007). However, considering the high demand for petroleum products worldwide, its use as a petroleum substitute appears to be its most fundamental application.

2.4.1.1. Bioethanol

Bioalcohols and biodiesel, are the two forms of liquid biofuels that appear to be central in delivering substitutes to petro-fuels (Demirbas and Demirbas, 2007). As a bioalcohol, bioethanol is the most widely used liquid fuel as it can be used as a gasoline blend or complete petroleum substitute. Bioethanol is fermented from sugars, starches or cellulosic biomass (Demirbas and Demirbas, 2007). As bioethanol is a renewable liquid fuel, coupled with its capacity to reduce environmental pollution, it becomes an important resource in reducing the consumption of crude oil and mitigating climate change. Specifically, if bioethanol is used to drive a light duty vehicle, the net CO_2 emission would be less than 7% of that from the same car using petroleum fuel (Bergeron, 1996).

It may seem that bioethanol is a recent discovery because it is a “modern” fuel, however, surprisingly, use of bioethanol as an alternate to petroleum fuel has been as early as 1880. Henry Ford originally designed the Ford Model T, a car produced between 1903-1926 to run completely on ethanol. Likewise, the inventor of the combustion engine, Nikolaus August Otto, designed his first invention to run on ethanol (Bucheit, 2002; Kovarik, 2003). However, when crude oil began being cheaply extracted, cars began using fuels from oil and ethanol therefore took to the sideline. But the oil embargo stirred up in the 1970s, characterised by a sharp rise in oil prices confirmed that industrialised and highly-developed nations were too dependent on fossil energy. Coupled with knowledge that fossil fuel sources are finite, attention was directed towards renewable energy resources. Only then did the potential of ethanol, as an automotive fuel, gain importance.

Currently the world produces 48 billion litres of ethanol per a year, with world production in 2005 being dominated by Brazil and the U.S. (Mathews, 2007b).

Table 2.1. World ethanol production for the year 2005 (Mathews, 2007b)

Country	Production (Million Litres)
United States	16 214
Brazil	16 017
China	3 800
India	1 700
France	910
Russia	750
South Africa	390

Brazil is the world's largest biofuel market with bioethanol produced from sugarcane being the first renewable fuel to be cost-competitive with petroleum fuel for transport (Xavier, 2007).

2.4.1.2. Biodiesel

On the other hand, in the European Union, biodiesel accounts for 80% of biofuels for transportation and 82% of total biofuels production (Bendz, 2005). Biodiesel is obtained by transesterification of renewable resources such as vegetable oils and animal fats, for use in diesel engines (Bendz, 2005; Demirbas and Demirbas, 2007). It has similar combustion properties to that of pure diesel but with lower viscosity, and can go almost directly into existing diesel vehicles or as a blend with fossil diesel (Bendz, 2005). Agricultural products grown as feedstocks for biodiesel include rapeseed, sunflower oil, jatropha oil, cottonseed and corn oils, however currently soybean oil is the main feedstock (Bendz, 2005; Demirbas and Demirbas, 2007). Often, these feedstocks are the result of specific cultivation of bioenergy crops, and in the case of bioethanol, sugarcane, corn and sweet sorghum are typical examples.

2.4.1.3. Biomethanol

Biomethanol is also another possible replacement for conventional motor fuels (Demirbas, 2007). It was previously used to power automobiles before the introduction of inexpensive gasoline, with synthetically produced methanol widely used as a motor fuel in Germany during the World War. Biomethanol is currently produced worldwide by conversion derived from syngas, natural gas, refinery off gas, coal or petroleum (Demirbas and Demirbas, 2007).

2.4.2. Biogas

Biogas production is a biomass energy technology that uses organic matter, such as animal wastes, sewage sludge or any biodegradable feedstock to produce biogas in an anaerobic environment (Johnson and Rosillo-Calle, 2007). Dedicated energy crops can also be used as feedstocks, such as cassava, maize or wheat. Biogas mainly comprises methane as well as carbon dioxide which can be used for electricity generation (Johnson and Rosillo-Calle, 2007). In India over a million biogas plants have been installed and in China about 25 million people rely on biogas digesters for cooking and lighting (Hall and House, 1995). Specifically, methane gas can be used directly for heating or cooking or it can be used for electricity production (Johnson and Rosillo-Calle, 2007). Biogas can also be used for transport applications in a compressed form as natural gas and further be upgraded (cleaned of impurities) and then fed into natural gas pipelines (Johnson and Rosillo-Calle, 2007). Biogas as transport fuel is commonly used in fleet vehicles and busses in cities such as Stockholm and in the midwestern region of the U.S.

2.4.3. Electricity Cogeneration

Undoubtedly, Mauritius serves as the prime example of extensive cogeneration using sugarcane bagasse (by-product of sugarcane processing) as the biomass feedstock. Cogeneration produces both process heat and electricity, allowing the country to generate close to 25% of its electricity in this manner (Deepchand, 2001). Potential benefits of cogeneration appear to be indirect, which include increased incomes for smallholder sugar farmers as in the case of Mauritius (Karekezi, 2002). Electricity cogeneration from sugarcane residues delivers several sustainable opportunities forming a major part of the sugar and power industries. Further opportunities are evident through energy conversion and efficiency measures by minimising the amount of cogenerated energy utilised in cane processing and exporting this energy to the national grid (Deepchand, 2005).

2.5. Sugarcane as a bioenergy crop

From the preceeding sections, it can be summarised that bioenergy supplies can be divided into two broad categories: (1) Organic municipal waste and residues from the food and materials sector, and (2) specific bioenergy crops cultivated for the production of bioenergy (Demirbas, 2007). The latter is of particular significance to this study as this study focuses on sugarcane cultivation for bioenergy purposes. Sugarcane, a tropical perennial grass, has been isolated as the crop of choice due to its high tonnage yields, high photosynthetic efficiency, lowest production cost and best energy balance in comparison with other crops. Furthermore, in addition to sugar, sugarcane processing produces multiple products and co-products with a diversity of applications that can be exploited even outside the bioenergy sector. For example, cane trash, the tops and leaves left after cane harvesting, can be used as animal feed and for soil conservation (Mungaroo *et al*., 2007). Other miscellaneous products include rum, which forms part of a highly profitable alcohol industry, as well as vinegar and perfumes (Alexander, 1985; Mungaroo *et al*., 2007).

As a bioenergy crop, its remarkable physiological, anatomical and agronomic features, makes it an integral biomass resource, with massive bioenergy generating potential (Alexander, 1985). Specifically, there are two discrete biomass products from sugarcane; lignocellulose and fermentable solids with potential numerous subproducts from each (Alexander, 1985). Lignocellulose which forms 70% of the plant can be used to produce several fuel products such as methanol, boiler fuel, and ethanol as well as industrial feedstocks and glucose syrup (Alexander, 1985). Fermentable solids constitutes the remainder of the plant which in addition to producing sugar, is the feedstock for ethanol production (Alexander, 1985). Bagasse and molasses are two such biomass products that has extensively been used in the energy sector, i.e. for electricity cogeneration and ethanol production, respectively. Cane trash, not a direct by product of sugarcane processing, rather a residue of cane cultivation is also used in conjunction with bagasse as a renewable energy resource (Dellepiane *et al*., 2003). Considering the points discussed, sugarcane undoubtedly is one of the most efficient bioenergy crops. Reflecting upon current energy trends characterised by depletion of fossil fuel stocks especially petroleum fuels for the transport sector, increasing worldwide energy demands and the negative environmental impacts associated with fossil fuel combustion, sugarcane as a bioenergy crop then gains new importance. This section will therefore discuss sugarcane as a bioenergy crop, particularly for ethanol production and cogeneration.

2.5.1. Bioethanol

Ethanol can be produced from other crops such as corn, sweet sorghum and cassava, but sugarcane is much superior to other crops with regards to efficient ethanol production (Blume, 1985). For example, corn, a temperate crop, requires twice as much land for cultivation to produce the same volume of ethanol that can be produced from sugarcane, because it is a low yielding crop (Xavier, 2007). It has a much worse energy balance and does not have the environmental benefits of cane-based ethanol (Johnson and Matsika, 2006). Furthermore, if ethanol is produced in large quantities from low-yielding crops, it could have negative environmental impacts and may generate more GHG emissions than do petroleum fuels (Xavier, 2007). In some cases where the factory is fired from coal-based sources, the energy and carbon balance can be negative compared to petrol (Farrel *et al*., 2006). In addition, for export markets the most efficient feedstocks are needed which then makes sugarcane the favoured ethanol feedstock (Johnson and Matsika, 2006).

2.5.1.1. Ethanol production

For ethanol production, sugarcane is prepared in the first stage in the same way as for sugar production (Blume, 1985). The cane is washed and crushed followed by a separation of the juice and fibre known as bagasse. The process of crushing involves shredding the cane and crushing it through several horizontal rollers to extract the juice. Subsequent steps are aimed at purifying the juice, followed by centrifugation to crystallise the sucrose, separating it from the ethanol. If only ethanol is to be produced, centrifugation is omitted and the cane juice is only purified. However, if ethanol and sugar are to be produced, all processing steps are needed including several rounds of centrifuging, which yields another byproduct called molasses. Ethanol can then be made from the molasses or cane juice or a mixture of both (Blume, 1985; Johnson and Matsika, 2006).

According to John and Matsika (2006), there are opportunity costs involved for a sugar producer who also makes ethanol. Specifically, when sugar prices are high, a producer who is capable of making both sugar and ethanol can use molasses as a feedstock for ethanol because the extraction from sugarcane is to be maximised. Conversely, when sugar prices are low, the producer can use high grades of feedstock (molasses and cane juice) as they contain more fermentable sugars, increasing the yield of ethanol production.

2.5.2. Electricity cogeneration

Among agricultural residues, sugarcane waste as a renewable energy resource is significant because it is produced in abundance (Dellepiane *et al*., 2003). One such residue previously mentioned is bagasse. It is the fibrous residue remaining after cane is crushed for juice extraction and after drying it is used to generate steam and power (Blume, 1985). Bagasse has always been the major source of combustible produced from sugarcane processing to meet the energy requirements of further processing pathways (Deepchand, 2001). It affords the sugarcane factory to be self sufficient in meeting its energy needs (Deepchand, 2001). All sugarcane factories use bagasse to generate steam to drive the factory equipment and turbo-alternators to produce electricity which powers the electric motors in the factory (Deepchand, 2001). In a number of cases where the factory is being operated efficiently, bagasse may be available in surplus. This then can be used to generate electricity which can be sold to the national grid. Such is the situation in Mauritius, where bagasse cogenerated electricity currently provides 20% of the energy and 25% of the country’s electricity needs (Mungaroo *et al*., 2007). Utilising bagasse in this manner also delivers environmental benefits by displacing emissions from fossil fuels and alleviating GHG emissions.

In addition to bagasse, cane trash also called *barbojo* in Latin America, is another residual fuel available to all sugar factories (Gabra and Kjellström, 1995; Dellepiane *et al*., 2003). Its main use is as a blanketing effect on soil which improves weed and erosion control, retention of moisture in the upper level, as well as adding organic matter and important minerals (Gabra and Kjellström, 1995). However, after satisfying these soil requirements, excess cane trash can be collected and used as a fuel source. This would represent a better option as burning of cane trash results in the release of a high level of atmospheric pollutants (Dellepiane *et al*., 2003). It has been suggested that cane trash represents a fuel resource of the same magnitude as bagasse (Gabra and Kjellström, 1995).

2.5.3. Vinasse

Stillage or vinasse is a byproduct of ethanol production and is produced in large volumes. Specifically, each litre of ethanol produced is accompanied by 10-15 litres of vinasse (Johnson and Rosillo-Calle, 2007). It contains unconverted sugars, non-fermented carbohydrates, dead yeast and a variety of organic compounds, which overall is a potentially valuable input for further bioenergy production as well as for other uses such as fertilisers (Cortez *et al*., 1998; cited in Johnson and Rosillo-Calle, 2007, pp24). The organic components can be used for biogas production through anaerobic digestion to produce methane. Another possible use is recycling it in the fermentation process, in which it could be partly used to dilute the sugarcane juice or molasses. Thus, as opposed to disposing vinasse which has potentially harmful environmental implications due to its high biological oxygen demand, it can be further processed for bioenergy production.

2.5.4 Household Gel-fuel

As outlined, sugarcane is used to produce ethanol as fuel, neat or blended with gasoline, however in addition to exporting for foreign fuel markets, other opportunities for rural and urban markets exist. One such opportunity is the production of gel-fuels from ethanol, as an alternate to paraffin (Chemical Technology, 2005). It is a safe and clean renewable cooking fuel that is promoted in several African countries (Ultria, 2004). Because it is a clean fuel, it reduces or altogether eliminates the health impacts caused by indoor air pollution associated with the traditional use of biomass and coal (Goldemberg *et al*., 2004).

2.6. Bioenergy implications for Africa

Although a number of sub-Saharan African countries have significant unexploited reserves of fossil fuels, the prospects for major increases in fossil fuel supply are constrained due to the unequal distribution of reserves (Karekezi, 2002). It is estimated that over 80% of sub-Saharan Africa’s oil reserves are in Angola and Nigeria, with 90% of the region’s coal reserves being located in South Africa (World Energy Council, 1992). However, on the other hand, renewable energy resources are relatively well distributed in the region, with the potential to provide enormous opportunities that will bring an “environmentally sound and secure energy future for Africa’s poor closer to reality” (Davidson and Karekezi, 1992).

Amongst all major world regions sub-Saharan Africa has the largest bioenergy potential, after accounting for food production and resource constraints (Smeets *et al*., 2004; Mathews, 2007b). This high potential is a result of the large areas of available cropland and the low productivity of existing agricultural production systems (Johson and Matsika, 2006). Specifically, the Food and Agricultural Organisation (FAO) Terrastat database (2003) indicates that 1.1 billion hectares of potentially arable land in sub-Saharan Africa, of which 158 million hectares was under cultivation in 1994, and by extrapolation would mean that 197 million are under cultivation today (Mathews, 2007b). Essentially, this leaves over 900 million hectares in Africa being available for biomass cover including the cultivation of dedicated bioenergy crops.

In industrialised countries, concerns over energy security and the necessity for reduction in GHG emissions, drives the need to find alternatives to petrofuels, such as biofuels (Mathews, 2007a; Mathews 2007b). However, it is not feasible for these industrialised countries or the North, as they are commonly referred to, to produce sufficient biofuel output to meet their growing energy requirements (Mathews, 2007b). As the head of the International Energy Agency, Claude Mandil puts it, “the energetics are against it, the land availability is against it, and the disturbances to the markets for corn and grain (the principal feedstocks in the U.S.), and to sugarbeet, the principal feedstock in the EU, would be far too great" (cited in Mathews, 2007b, pg. 3554). Therefore, due its large bioenergy potential, Africa, referred to as the South, becomes an attractive investment.

According to Mathews (2007b), a Biopact between the North and South could drive industrial development and "spell an end to poverty". However, whether the South opts to negotiate a Biopact with the North, there are still several benefits for the South in investing in renewable energy technologies. These include health improvement, reduced regional emissions and creation of rural livelihoods as well as advantages arising from reduced dependence on imported sources of energy (Johnson and Matsika, 2006). Furthermore, as millions of people in sub-Saharan Africa lack access to energy or at least a reliable source of energy, an expansion of renewable energy sources such as bioenergy becomes key in bringing reliable energy to the rural and urban poor (Lefhoko, 2005).

Fortunately, there is already some experience in Southern Africa with bioenergy, particularly in Malawi and Zimbabwe with ethanol blending (Johnson and Matsika, 2006). Zimbabwe began its programme in 1980 and blended ethanol with petrol until 1992, when a severe drought brought production of sugar and ethanol to a standstill (Johnson and Matsika, 2006). Eventually, due to a lack of government support, ethanol blending was phased out, however there is a possibility that due to the recent phasing out of leaded petrol, ethanol blending programmes may be revived. In Malawi, ethanol production began in 1982 and has continued uniterrupted. Currently, the Democratic Republic of Congo and South Africa are the largest producers of biofuel crops (Johnson and Rosillo-Calle, 2007). With the advent of Ethanol Africa, by 2008, South Africa would be producing 500 000 litres ethanol every day, using maize as a feedstock (AfricaFiles, 2007). In addition it will also produce other byproducts such as ethanol gel and DDGS which has a high protein content suited to stockfeed that can replace imported soyabean cake.

However, as already outlined, there exists potential for further expansion and investment in the bioenergy sector. The vast numbers of existing cane-producing industries in Southern Africa and vast tracks of available uncultivated land, confirms the great potential for subsequent bioenergy production in the region (Karekezi and Kithyoma, 2003). Overall, Southern Africa has a high share of population engaged in agriculture, significant amount of land potentially available for alternative uses and plentiful biomass resources which create significant opportunities for increasing biomass use in the region as well as the potential for exports (Johnson and Rosillo-Calle, 2007). The best summary of Africa's bioenergy potential is provided by chief executive of Ethanol Africa, Johan Hoffman: "Africans have the potential to become the Arabs of the biofuel industry", and "Africa has the potential to provide energy for the world-who is going to supply the growing economies of China and India? We already know there is a finite amount of oil left in the Earth, and it is being used in enormous quantities and will soon be gone." (AfricaFiles, 2007).

2.7. Negative impacts of Bioenergy

Despite the multitude of benefits associated with bioenergy, there are still concerns arising from increased bioenergy use. For a bioenergy programme to be sustainable, the negative impacts have to minimised or at best all together avoided.

2.7.1 Land use

One of the central conflict areas in cultivating bioenergy crops is the issue of land use. According to Fritsche *et al*., (2006), depending on its spatial distribution and cultivation practices, bioenergy cropping could result in the loss of habitats and the endangerment or extinction of rare species, obstruction of migration patterns, degradation of soils and water bodies. Therefore, the land-use effects of bioenergy cropping systems must be considered with reference to current land use. Furthermore, a critical argument concerning land use is that of competition between the use of land for food production and bioenergy crop cultivation. This conflict has sparked the 'food versus fuel' debate (Alexander, 1985; Cornland *et al*., 2001; Kartha *et al*., 2005; Fritsche *et al*., 2006). However, on the contrary bioenergy crops could be a means of alleviating poverty and improving food security through income generation. An important note is that global food production is sufficient to feed all individuals, but distribution of food is uneven (a result of unequal economies and power struggles) which is the central cause of poverty (Addison, 2005; cited in Baijnath, 2005, pp 41).

What supporters of the ‘food versus fuel’ debate do not take into consideration is the possibility of using marginal or abandoned land for cultivation (Smeets *et al*., 2004; Kartha *et al*., 2005). For example, in Brazil cultivation of sugarcane for bioethanol has expanded to degraded or poor land, mainly extensive pastures (Pinto *et al*., 2001). Furthermore, many biofuels are produced from residues of bioenergy crop processing, after the ‘feed’ portion of the crop has been extracted (Baijnath, 2005). This is the case of sugarcane cultivation, such that bioethanol is produced from the byproducts of cane processing like molasses and bagasse.

In order to avoid these negative impacts, the present study, therefore aims to exclude areas currently under cultivation for food and protected areas. In addition, it is further based on the arable land available in the study area (Angola) after food production, calculated by Van Den Berg and Rademakers (2007) using the United Nation’s population projections and FAO food demand estimates for 2030 and 2050.

2.7.2. Loss of biodiversity and deforestation

Apart from land use, it is suggested that conflicts between biodiversity and bioenergy crop cultivation are also possible (Fritsche *et al*., 2006). There is a significant risk that unless controls are put into place, the increasing demand for fuels will result in damage to biodiversity rich habitats (Birdlife International, 2005; Fritsche *et al*., 2006). This is the case for soy expansion in South America which is driven by exports to Europe and other industrialised countries which could potentially severely reduce biodiversity in the Cerrado area (Kaltner *et al*., 2005). However, unlike soy expansion, sugarcane expansion in Brazil provides reassurance for concerns over biodiversity loss, as it is cultivated on degraded or poor land and not on new uncultivated land (Kaltner *et al*., 2005).

Furthermore, the implementation and acceptance of biofuels faces several critics, arguing on several issues ranging from the overall sustainability of biofuels to its impact on global climate change. Deforestation features highly amongst these issues, with the central focus being the palm oil industry. Palm oil is used to make biodiesel and biofuel-critics have accused the industry of large-scale deforestation (Friends of the Earth, 2004; Brown and Jacobson, 2005). As a result some have even tagged biofuels as 'deforestation diesel' (ORC, 2007). Malaysia and Indonesia face heavy criticism, with some suggesting that "many thousands of square miles of tropical rainforest have been cleared for oil plantations" (Brown and Jacobson, 2005). However, these criticisms have not gone down lightly, with the oil-palm industry claiming to having established plantations on land already used for agriculture. Specifically, Malaysia has responded to criticisms by stating that oil palms in Malaysia are mainly established on old agricultural land and previously logged-over forest land (Malaysian Palm Oil Council, 2006). Furthermore Malaysia boasts sustainable forest management which enables extraction of certified timber.

Irrespective of closed circle arguments, loss of biodiversity and deforestation should be avoided at all costs. Controls such as international certification schemes are means of ensuring that bioenergy crops are not causing environmental destruction and biodiversity loss in those regions (Birdlife International, 2005). This would encourage sustainable cultivation practices, and mitigate or avoid the negative impacts placed upon biodiversity rich habitats.

2.7.3. Potential GHG emissions

One of the benefits encouraging interest in bioenergy is its potential to reduce GHG emissions since its use is carbon-neutral. However, cultivation of bioenergy crops may actually contribute to GHG emissions! (Fritsche *et al*., 2006). Specifically, the overall balance of GHG emissions from bioenergy supply depends on the effective use of byproducts from bioenergy conversion and processing which could offset some of the GHG emissions. At the same time, nitrous oxide (N_2O) emissions, both from fertiliser applications and the production of fertilisers could partially offset CO_2 neutrality (Fritsche *et al*., 2006). Also, if fossil fuels are utilised in bioenergy production and downstream processing, especially if coal is used to process energy, net GHG savings may be reduced.

Sugarcane cultivation for bioenergy purposes appears to offset these detrimental effects. First, cane processing produces several byproducts, which are directed for further bioenergy use, thereby in actuality reducing GHG emissions. Second, with the exception of the first generation ethanol production, bagasse, rather than coal, is used to process energy.

2.7.4. Soil erosion

It has been suggested that increases in annual bioenergy crops could lead to further soil erosion as a result of the overuse of irrigation, agrochemicals and heavy harvesting equipment which can degrade fertile soils (Fritsche *et al*., 2006). By contrast, appropriate bioenergy farming systems could be operated on degraded land, as in the case of sugarcane in Brazil, which could increase soil carbon and restoring land for sustainable use. Furthermore, perennial bioenergy crops, such as sugarcane, could improve soils and reduce erosion on arable land currently in use by creating year-round soil coverage (Fritsche *et al*., 2006)

2.7.5. Water use and water contamination

Water use becomes a serious problem in agricultural practices, especially in regions where water is scarce and highly variable throughout the year (Fritsche *et al*., 2006). If a crop requires irrigation to supplement water requirements from rainfall, i.e. an increase in irrigated land, it could lead to water scarcity, a lowering of water tables and reduced water levels in rivers and lakes. In addition, concerns are also fostered over potential contamination of water sources by agrochemicals (pesticides and fertilisers) applied during cultivation.

Excessive water consumption has been a major concern in sugarcane cultivation. It is estimated that 1500 to 3000 litres of water is used to produce just 1kg of sugar and in the milling and processing phase, 3 to 10 m^3 of water is required to wash every ton of cane

(Clay, 2005). This leads to overexploitation of water resources bearing cumulative impacts associated with expanded production. In order to avoid this, Clay (2005) suggests that the goal should be of increased efficiency, that is “more crop per drop”. One way is to improve technology, and/or the introduction of more water efficient cane varieties. Within the milling and processing phase, recycling of water, which is already being done in mills, will alleviate some of the water concerns associated with cane cultivation.

Water use is especially relevant in the Southern African context as global climate change models suggests that rainfall much over this region will decrease and become more erratic (Hulme *et al*., 2001). Thus, due to the effects of climate change there is a growing concern about future agricultural water requirements and water availability (Fischer *et al*., 2002).

2.8. Conclusion

The several advantages of bioenergy spans social, economic and physical sectors, thereby making it a highly attractive source of renewable energy. Specifically, the potential opportunities associated with its implementation are particularly relevant in the developing world, especially social upliftment and employment generation. The preceding sections have served to provide an overview of bioenergy, both globally and in a developing world context. In this chapter sugarcane has been introduced as a bioenergy crop. The next chapter will outline the ecology of sugarcane as the ecological considerations are those which would be included in the land suitability analysis for sugarcane cultivation.

Chapter 3

Ecology of Sugarcane

3.1. Introduction

The previous section introduced sugarcane as a bioenergy crop and outlined its several applications. However, for the purpose of this study, to delimit areas suitable for sugarcane cultivation, sugarcane in its ecological sense has to be addressed. This chapter therefore serves to give an account of sugarcane and its ecology, as these are the factors against which available land will be assessed and deemed suitable for sugarcane growth.

3.2 Origin of Sugarcane

Sugarcane has been known for at least 2000 years and in ancient times was referred to as 'honey produced from reeds' as described by Theophrastus, whilst Discorides described it as 'honey with the consistency of salt which could be crunched between the teeth' (Sharpe, 1998). Sugarcane is thought to have originated in the Pacific Islands or Southeast Asia, most probably in New Guinea some 17 000 years ago and subsequently spread through India (Mukerjee, 1957; Alexander, 1985; Schwartz, 2004). The Arabs were responsible for much of its spread as they took it into Egypt during their conquests in 641 AD and it further spread by this means to Cyprus, Syria, Crete and Spain (Purseglove, 1979).

Sugarcane belongs to the genus *Saccharum* L. and is classified as a grass, therefore a member of the *Gramineae* family, tribe Andropogonoae (Alexander, 1985, Sharpe, 1998). Six species are included in the classification of sugarcane: *officinarum*, *spontaneum*, *barberi*, *sinense*, *edule* and *robustum*, all of which grow in tropical and sub-tropical environments (Tarimo and Takamura, 1998). According to Mukherjee (1957), of these, the cultivated canes include three species: (1*)* The noble canes belonging to *Saccharum officinarum* L.; (2) *S. barberi* Jesw known as the North Indian canes and (c) *S. sinensis* which are the Chinese canes and the Pansahi group of Indian canes.

3.3 Ecology

3.3.1. Latitude, Altitude and Terrain Requirements

Sugarcane is most suited for tropical climates and is grown primarily in tropical regions (Sharpe, 1998). According to Duke (1983), sugarcane requires a hot, humid climate, alternating with dry periods. Most of the world's sugarcane is grown at latitudes between 33°N and 33°S, with yield decreasing rapidly as cane is moved above latitudes of 30 (Griffee, 2000). Additionally, elevation is an essential factor determining sugarcane growth success and typically the crop is cultivated on land that is up to 1600m above sea level (Griffee, 2000). At higher altitudes the growth cycle has been observed to be longer.

Furthermore, much success is noted with cultivation at low elevations or slightly sloping land (Duke, 1983). In conjunction with biophysical requirements, there appears to be non-biophysical impacts of sugarcane's terrain requirements, as suggested by Sys *et al*., (1993). Specifically, level terrain appears important in commercial farming with steep slopes posing constraints on mechanical cultivation. Steeper slopes are cultivated by peasants or small-scale farmers and as a result labour costs will be higher. Hence, Griffee (2000) adds that productivity of sugarcane cultivated on flat land is higher compared to cultivation on hillsides.

3.3.2. Soil

As a result of its versatility, sugarcane can be grown successfully under a wide range of soil conditions (Fauconnier, 1993, cited in Cornland *et al*., 2001, pp 33). According to Tarimo and Takamura (1998), sugarcane is a heavy feeder crop and requires soils to have optimum properties, including both physical and chemical characteristics. It is suggested that the physical properties of the soil are more critical than the chemical characteristics, such that porosity, depth, bulk density, permeability and moisture retention, are more crucial to successful sugarcane production (Cornland *et al*., 2001). This is a result of the ease with which chemical properties can be modified, either by adding fertilisers or nutrients to the soil, whereas variables such as porosity are intrinsic and thus, cannot be modified (Cornland, *et al*., 2001).

3.3.2.1 Physical Requirements

For successful sugarcane cultivation, soils should be well-structured, aerated and granular in structure (Sys *et al*., 1993). This would ensure that the soil would have efficient water storage (approximately 150mm water content) and drainage characteristics, thereby avoiding viruses, diseases and bacterial infections associated with poorly drained and water-logged soils (Schulze *et al*., 1997). The ideal soil type would therefore be loam composed of adequate proportions of clay, sand and silt (Sys *et al*., 1993). In addition, sugarcane grows better on deep, fertile soils, with the optimal depth for cane cultivation being in excess of 1m (Schulze *et al*., 1997).

3.3.2.2 Chemical Requirements

3.3.2.2.1. Nutrients

The key macronutrients essential to optimum cane growth are Nitrogen (N), Phosphorous (P), Potassium (K).

- N is the essential nutrient for vegetative growth and is recommended to be applied in the form of urea at 130 kg N/hectares (ha) (Cornland *et al*., 2001). However, FAO AGL (2002) suggests that for 100 ton/ha sugarcane, N be added at the level of 100-200 kg N/ha. Application of N should be carefully monitored as excess N can potentially depress the sugar content of the juice (Cornland *et al*., 2001).
- P is essential for cane growth, with deficiencies retarding development of the root system. To obtain a yield of 100 ton/ha sugarcane, it is recommended that P be applied at the level of 20-90 kg P/ ha (FAO AGL, 2002). It is suggested that P be placed close to the plant because of low mobility in the soil (Cornland *et al*., 2001).
- K plays an important role in counteracting the effects of N on the sucrose content of the cane juice. It should be applied in the form of Potassium chloride at a concentration of 80 kg K/ha, and K in excess of this would add to the K reservoir of the soil (Cornland *et al*., 2001).

In addition to these, the levels of Calcium (Ca) and Magnesium (Mg) should be monitored to avoid potential growth retardation, reduction in resistance to diseases and even plant death (Sys *et al.*, 1993). It is important to note that prior to applying macronutrients according to the levels suggested above, soil nutrient analyses should be conducted to avoid over-fertilising. Soils in different geographical regions under different conditions would exhibit varying amount of the essential N, P and K.

3.3.2.2.2. pH and Salinity

The pH of the associated chemical environment influences the solubility of some nutrients, therefore soil pH regulation becomes essential for successful cane growth (Cornland *et al.*, 2001). There is a potential for certain nutrients such as toxic Aluminium, to become more soluble at low pH with the risk of leaching down through the soil profile in the water supply (Cornland, *et al*., 2001). The optimum pH range for sugarcane is 6.0-7.5 but sugarcane being as versatile as it is, can tolerate a pH range of 4.5-8.5 (Blume, 1985; Tarimo and Takamura, 1998; Cornland *et al.*, 2001). Soil acidity should therefore be monitored and regulated, as low pH may affect microbial activity within the soil, hence affecting nutrient cycling (Cornland *et al*., 2001).

Coupled with this, cane can moderately tolerate saline conditions. It has been observed that crop yields decrease with increasing salinity, therefore for there to be no impact on cane yields, it is suggested that the electrical conductivity of the soil solution should be less than 2.0 dS/m (Griffee, 2000; FAO AGL, 2002).

3.4 Climatic Requirements

3.4.1. Temperature

According to Tarimo and Takamura (1998) like all other tropical cereal grasses, sugarcane requires an optimum temperature for effective germination of sett, tiller elongation, photosynthate mobilisation and ripening. The minimum mean air temperature for active growth is 20°C, with growth arresting when temperatures fall below 15°C and exceed 38°C (Blume, 1985; Tarimo and Takamura, 1998; Cornland *et al.*, 2001). Specifically, temperature requirements for each phase of the growth cycle are:

- Germination – above 8.5°C (Grifee, 2000), optimum 27-33°C (Tarimo and Takamura, 1998). Schulze *et al*., (1997) has suggested an optimum of 22 – 32°C. Germination is slow at soil temperatures below 18°C and increasingly rapid up to 35°C (Bull, 2000)
- Sprouting and Rooting – above 20°C
- Stalk elongation – optimum of 23°C (Tarimo and Takamura, 1998)
- Ripening (phase at which sucrose level increases) – optimum range of 10-20°C (Griffee, 2000).

3.4.2. Insolation

Sunshine or insolation is another important factor to consider when growing sugarcane. Levels of light intensity affect photosynthetic rate, which has some influence on crop yields (Cornland *et al*., 2001). According to Griffee (2000), the greater the solar radiation, greater the cane production, as high levels of radiation are important in the rapid growth phase and in the ripening period to ensure high levels of sucrose in cane. The optimum radiation requirement is in excess of 2 200 hours sunshine/annum with the minimum being 1200 hours per annum (Blume, 1985; Sys *et al*., 1993). In addition, solar radiation enhances the absorption of mineral nutrients during the day and equally dependent upon insolation is water absorption (Tarimo and Takamura, 1998).

3.4.3. Water Requirements

3.4.3.1 Rainfall

Although sugarcane is a drought tolerant crop, it nevertheless is a highly water demanding crop, especially during the peak growing phase (Hunsigi, 1993; cited in Cornland *et al*., 2001, pp 34). Adequate available moisture is essential throughout the growing period as vegetative growth, including cane growth is directly proportional to the amount of water transpired (FAO AGL, 2002). The crop requires a mean annual rainfall supply of 1200 – 1500mm, evenly distributed throughout the growing season (Blume, 1985; Tarimo and Takamura, 1998, FAO AGL, 2002). Specifically, a mean annual rainfall of 850mm, optimally 1300mm (ideally 120mm per month) should be followed by a dry, but sunny and frost free winter ripening and harvesting period (Schulze *et al*., 1997).

3.4.3.2 Irrigation

If rainfall is insufficient (less than 800mm/annum) then supplementary irrigation becomes essential to meet growth requirements (Watson and Garland, 2004; Tarimo and Takamura, 1998). As each development phase of sugarcane has different growth requirements, the frequency and depth of irrigation should vary with the growth periods of the crop (FAO AGL, 2002). Preferred irrigation applications for each growth phase is summarised in Table 3.1.

Table 3.1. Irrigation requirements of sugarcane during each growth phase (FAO AGL, 2002)

Growth Phase	Irrigation Requirement
Emergence & establishment of young seedlings	Light, frequent applications
Early vegetative phase	Early flush of tillers - this furnishes shoots of approximately the same age
Stem elongation & early yield formation	Intervals between irrigation applications can be extended but depth of water should be increased*
Ripening period	Irrigation levels are extended or altogether stopped when it is necessary to bring the crop into maturity
Yield formation	Irrigation intervals extended or halted**

*Adequate water supply during this period of active growth is essential as with adequate water supply this period is reached earlier and total cane height is greater.

** Frequent irrigation will accelerate flowering which reduces sugar production, therefore to increase yield irrigation intervals are extended or halted.

In general, irrigation allows producers to grow high-volume crops that would otherwise not be possible due to low rainfall (Dumler and Rogers, 2006). Specifically, average crop yields are higher under irrigated conditions compared to rainfed agriculture (Siebert *et al*., 2005). In the arid region, irrigation is a prerequisite for crop production, whereas in the semi-arid and humid areas, irrigation serves to increase yields and attenuate the effects of drought.

3.4.4. Relative Humidity

According to Schulze *et al*., (1997), a relative humidity of less than 70% is required during the maturity and harvesting phases. It is in these phases at which relative humidity is most crucial, as diseases become more prevalent with higher humidities (Baijnath, 2005).

3.5. Sugarcane Growth

Depending on the variety, the growing period of sugarcane, from planting to maturity, spans one to two years (Cornland *et al*., 2001). The stages in the cane growth cycle are germination, establishment, stem elongation, maturation and ripening. The time it takes to complete each phase is summarised in Table 3.2., according to FAO AGL (2002):

Table 3.2. Phases of sugarcane growth

Phase	Period (days)
Germination & Establishment	10 - 30
Stem elongation	150 - 350
Maturation (yield formation)	70 - 200
Ripening	50 - 70

3.5.1 Germination and Establishment

Sugarcane is usually produced from cuttings called setts, which are stalks cut into shorter segments (Tarimo and Takamura, 1998, Willcox *et al*., 2000). Whole stalks can also be used as planting material (Willcox *et al*., 2000). To achieve a high percentage of germination, the setts are planted within a few days of harvesting and under optimal conditions, setts germinate within two weeks of planting. During the initial stages of germination, a flush of roots is produced which is important in maintaining the moisture in the sett. The shoots grow from underground nodes and the axillary buds on the nodes give rise to tillers (Tarimo and Takamura, 1998).

3.5.2. Stem Elongation

Early cane growth is characterised by stem elongation during which the fibre content of the stem is high (Bull, 2000). Breeding of modern cane varieties implies that the plant top is very heavy and consequently is prone to logging. As a response, stems curve again to grow upright.

3.5.3. Maturation and Ripening

During this phase, overall growth rate declines, and sucrose content increases approximately 120d after planting (Bull, 2000). Following stem elongation, each internode operates as an individual unit, it completes cell elongation and cell wall thickening and fills with sucrose. This sucrose can then be translocated to support further growth and tillering when conditions are not favourable for photosynthesis (Bull, 2000). As the stem matures, sucrose content continues to increase, and is the phase of yield formation (FAO AGL, 2002).

3.5.4. Harvesting

After a 12-18 month growth cycle, sugarcane is harvested by cutting the stems close to the ground (Bull, 2000). The remaining underground plant material, called the ratoon (root system), will resprout and develop into a new plant. A maximum of four ratoon crops (can be more than four as is the case in Southern Africa) are grown before ploughing out the crop and replanting, as ratoon crops accumulate damage from harvesting, weed control and possible pests and diseases, which result in yield reduction (Bull, 2000).

There are three primary methods of sugarcane harvesting: (1) manual, (2) semi-mechanised, and (3) fully mechanised (Cornland *et al*., 2001). In poorer countries or rural areas, manual harvesting is the method employed due to financial constraints, whereas semi-mechanised and mechanised harvesting operations have become more popular in wealthier, developed countries. Semi-mechanised harvesting implies that the cane is cut manually but loaded mechanically. With manual harvesting, the cane is first burned to clear out weeds, animals and debris that could potentially complicate cutting. With mechanical harvesting, the cane can usually be cut green, which results in a significant quantity of biomass leftover, called cane trash (Cornland *et al*., 2001). Cane trash is a significant biomass resource, and can be used to generate bioenergy (Dellepiane *et al*., 2003).

3.6. Cultivation

To cultivate sugarcane, several factors have to be addressed which include having to choose the cane variety, preparing the land for cane growth, managing weeds and pests, and supplying the crop with an ample supply of fertilisers and water. The capacity and resources to meet these requirements for cane cultivation will influence the location and feasibility of a commercial sugarcane plantation.

3.6.1. Cane Variety

Choosing the cane variety is an important factor in cane production, as it will determine the potential yield of a plantation as well as resistance to pests and disease (Cornland *et al*., 2001). The specific variety chosen will be depend on the climatic, ecological and economic conditions (Cornland *et al*., 2001).

3.6.2 Land preparation, Fertilisers and Water supply

The land selected for cane growth would require immense preparation prior to planting. Clearing of the land, soil preparation, leveling and grading of the land, weed and insect control, ploughing and irrigation, are steps undertaken to prepare the land for cultivation (Alexander, 1985; Blume, 1985). Following planting, the addition of fertilisers assists in meeting the plant’s nutrient requirements during growth and development and improving crop yields (Blume, 1985). As sugarcane is a highly water demanding crop, adequate water supply is required throughout the growing period. If rainfall cannot meet the crop's water requirements, irrigation then becomes essential if mean annual rainfall is less than 800mm (Watson and Garland, 2004).

3.6.3. Transportation to the mill

The quality of sugarcane starts to deteriorate immediately following harvesting, and it is suggested that to avoid loss of sugar content, it is essential to avoid long delays between harvesting and milling of the cane (Cornland *et al*., 2001). These delays further decrease overall profitability of sugarcane production. It has been recommended that generally distances of 50-80 km be the limits for a mill supply area (Baijnath, 2005; Tomlinson, 2005; cited in Grimmet, 2005, p11).

3.6.4. Weeds, pests and disease control

For the first three months of growth, sugarcane requires a weed-free environment, as weeds can drastically reduce yields (Cornland *et al*., 2001). Weeds compete with sugarcane for water and nutrients and harbour pests which affects sugarcane productivity (Cornland *et al*., 2001). Depending on the type of weed, conditions and degree of infestation, manual, mechanical or chemical methods can be used to control weeds. In addition to weeds, pests also pose a threat to sugarcane growth and development. Globally, the major sugarcane pests are, moth borers, froghoppers, termites, white grubs and rodents which can be controlled and eliminated using agricultural methods without applying chemicals (Cornland *et al*., 2001).

Sugarcane is susceptible to an estimated 100 diseases, caused by various biological agents including bacteria, fungi and viruses (Hunsigi, 1993). The most important diseases are smut, downy mildew, ratoon stunting disease, red rot, leaf scald, and sugarcane mosaic virus because they are systemic (already present within the cane stalk) (SASEX, 1980; Cornland *et al*., 2001). Disease control in sugarcane is achieved by selecting resistant varieties and establishing these varieties in the sugarcane plantation (SASEX, 1980). Other treatments include long hot-water treatments (50°C at 3 hours) for ratoon stunting disease and short hot-water treatments (50°C for 30 minutes) (SASEX, 1980).

3.7. Sugar production

About 200 countries grow sugarcane primarily as a source of sugar with a world sucrose production of 55 million ton/year (FAOSTAT, 2001). To produce sugar from sugarcane, cane juice is initally extracted from the cane through cutting, crushing and washing. The juice is then dried into crystals through an evaporation process using steam as a heat carrier (Gabra and Kjellström, 1995). Specifically, the juice is clarified by heating in the presence of lime which filters out some impurities and arrests sucrose decay to glucose and fructose. Following this, the cane juice is concentrated by evaporation to produce a syrup (Mackintosh, 2000). The syrup undergoes multiple rounds of crystallisation to extract the sucrose. It is then boiled, and upon cooling the sucrose crystallises out of the syrup. Centrifugation is used to separate the sucrose by crystallisation from the remaining liquid called molasses.

3.8. By-products of cane processing

Chapter 2 discussed the various bioenergy applications of sugarcane and its byproducts, therefore this section serves only to briefly summarise the main agricultural residues of sugarcane processing.

3.8.1 Bagasse

According to Blume (1985), about 13% of the sucrose in the cane is lost during processing with the production of several by-products. One such by-product is bagasse, which is the fibrous portion of sugarcane that remains after the juice has been extracted (Blume, 1985; Gabra and Kjellström, 1995; Deepchand, 2001). Due to its calorific value, 19 250 KJ/kg, bagasse has been traditionally used as boiler fuels in the mill to generate steam at high pressure and temperature (Blume, 1985; Deepchand, 2001). Excess energy can be directed to the electricity grid, a prime example being Mauritius in which 20% of the country’s current energy needs originate from bagasse (Deepchand, 2001).

3.8.2. Filter cake

During sugar production, the impurities filtered out by clarification with lime, produces the second by-product termed filter-cake (Blume, 1985). The filter cake is used as a fertiliser in the cane fields (Blume, 1985).

3.8.3 Molasses

Molasses is the thick syrup residue left after sucrose has been removed from the clarified sugar juice (Blume, 1985). It has a broad spectrum of uses, which includes serving as a raw material for animal feeds, a fertiliser, and used as a feedstock in the production of ethanol (Blume, 1985).

3.8.4. Cane trash

The material leftover in the field after harvesting such as the tops and leaves of plants is termed cane trash (Gabra and Kjellström, 1995). Although not a direct by-product of cane processing, cane trash also known as barbojo, can be used as a source of residual fuel (Gabra and Kjellström, 1995). In a study conducted by Dellepiane *et al*. (2003), it was shown that biogas obtained from bagasse and barbojo can be used in electrical power generation.

3.9. The non-biophysical considerations in sugarcane management

The ultimate aim of successful sugarcane cultivation should culminate with effectively managed sugarcane harvesting and delivery. To an experienced grower, the concern is not the production of high tonnages but rather getting this high tonnage harvested (Alexander, 1985). Thus, the main harvest objectives are:

a) To cut and remove the sugarcane tonnages from the field, in an economic manner, i.e. removal without damage to the seed bed, and;
b) To perform this step in such a manner that the harvested cane is acceptably clean (free of soil, adhering mud and other objects which can impair its milling) for its subsequent role as a biomass feedstock (Alexander, 1985).

Following harvesting, the most important component in sugarcane management would be its delivery to its agricultural and manufacturing phase, i.e. the mill (Alexander, 1985). As previously outlined in section 3.6.3, timeous transportation to the mill has implications for sugarcane quality and is a critical phase in the successful cycle of sugarcane production.

This study incorporates the logistics of the above-mentioned aspects into the land suitability assessment, in order to provide a general idea of the viability of establishing a sugarcane farm at the resultant suitable areas. This section therefore serves to provide an understanding of the logistics that frame sugarcane harvest and delivery. As the several practices of harvesting have been outlined previously, harvesting will be considered in terms of labour contribution

3.9.1. Sugarcane Harvesting

As this study promotes social and economic development in the study area, manual harvesting is promoted due to its high labour requirement. This would undoubtedly create economic and employment opportunities, alleviating Angola's extensive unemployment situation.

Manpower or labour in sugarcane harvesting, especially for the purpose of bioenergy, is considered most effective in "filling the gaps" created where machines are ineffective or incapable of performing satisfactory work (Alexander, 1985). Furthermore, a trained labourer has several associated advantages over mechanised cultivation (Alexander, 1985). These include:

- individual stem selection
- persistent clean cutting at a predetermined height
- stripping away of trash
- clean topping at a predetermined height
- piling stems in uniform alignment without contamination with soil or mud

In addition to these, the human cane cutter, is a preferred option when cane stands are prevented by circumstance from being harvested mechanically. Some of these circumstances include excessively high tonnage, excessively poor conditions caused by lodging or secondary rooting, as well as excessively steep or rough terrain (Alexander, 1985).

However, when considering manual sugarcane harvesting, it is essential to note that it is undoubtedly a labour-intensive option (for example, hand cutting), and as a result the physical state of the available labour force is critical consideration. Specifically the level and nature of human inputs is an important factor influencing the suitability of land for agricultural activity (FAO-IIASA, 2007). Factors such as health and education status are included in this consideration. For example the prevalence of HIV/AIDS surrounding the area selected for sugarcane farming would be an indication of how healthy the labour force is. If there is a high prevalence of HIV/AIDS there is an indication of high rates of turnover in terms of workforce, and that current workforce may not possess the desired physical capacities for manual harvesting. Another factor to consider is the level of education of the surrounding population, as those individuals with a high level of education would not necessarily partake in such labor-intensive positions. A high level of education, such as matriculation or a university degree would afford employment opportunities at sector specific and skilled positions.

3.9.2 Sugarcane transport – infrastructure considerations

According to Alexander (1985), transportation of sugarcane is dictated by the physical proximity of the sugarcane farm (agricultural phase) to the mill (manufacturing phase), with an ideal physical layout for an energy cane enterprise being the centralised location of the mill surrounded by the agricultural area. The are two fundamental types of cane transportation situations, which is characterised by intraplantation and inter-area transport.

3.9.2.1. Intraplantation transport

Intraplantation transport is a highly localised cane movement scenario and, transportation scenarios of this nature would utilise an internal road or rail network to transport harvested biomass. What makes this scenario attractive is the capacity to load a carrier unit in the field, deliver the load directly to the mill and return to the mill for another load, such that this trip can be repeated several times daily. This feature of intraplantation transport reduces costs especially in terms of fuel savings, and equipment expenditures. Additional advantages include greater carrier efficiency (tons/carrier day), reduced sugar and biomass losses and reduced vulnerability of feedstock supply (Alexander, 1985).

3.9.2.2. Inter-area transport

This transportation scenario transports harvested biomass already hauled from the field in one carrier to another carrier, to a milling site located a long distance away from the agricultural area. Justifying the use of inter-area transport for sugarcane is the poor economics of hauling by highway, and as a result the use of rail transport becomes necessary.

In practice, the choice of transportation scenario is highly dependent on costings, harvesting, loading and milling receiving facilitiies (i.e. proximity to agricultural area) (de Beer, 1998). As a result, there is no universally applicable means to determine which transportation scenario is most cost effective and practical at a particular site.

However, it can be undoubtedly stated that land productivity is dependent on services provided by transportation networks (FAO, 1985). Consequently, there is a requirement for an efficient road and railway transport infrastructure. In many instances, a properly maintained rail system offers the most cost-effective mode of transport, especially when considering delivery of high-tonnages over long-distances. Trains are highly effective in transporting large amounts of materials and products to distribution centres, where goods can be offloaded on to trucks (Nierengarten, 2007). However, for rail transport specifically, the cost of installing a new rail system usually makes this option less attractive (de Beer, 1998). According to de Beer (1998), an alternative would be to keep only the main lines with tractor-trailer rigs which could bring the cane to appropriate sidings.

Ethanol, a by-product of sugarcane processing also features in the cane transport cycle. As it is a highly flammable liquid, it requires the safest mode of transport. Rail transport, in such a case is considered the safest means of transporting ethanol (Richards, 2006). Furthermore, due to its corrosive nature, unlike other gasoline products, ethanol cannot be pumped through underground pipelines (Nierengarten, 2007). However, although rail transport provides the most practical means of transporting ethanol, other options such as transport by truck may also be exploited. It is beyond the scope of this project to determine which transport mode is most cost effective for both sugarcane and ethanol, and will therefore include both rail and road infrastructure as a delivery option.

3.10. Conclusion

Due to its remarkable physiological, anatomical and agronomic features, sugarcane as a bioenergy crop is an integral bioenergy resource. With its establishment as a bioenergy crop, it offers a wide range of by-products, including sugar, which has a variety of applications. These have been outlined in the preceding sections, including an account of the ecological requirements for successful sugarcane growth. The following chapter gives a description of the study area.

Chapter 4
Description of Study Area – Angola

4.1. Introduction

Since its independence from Portugal in 1975, civil war was the norm in Angola. The bitter rivalry between the ruling Popular Movement for the Liberation of Angola (MPLA) and the rebel group, the National Unit for the Total Independence of Angola (UNITA), fuelled anger, destruction and infrastructure breakdown. However, with the death of Unita leader Jonas Savimbi in 2002, a ceasefire was signed to end the conflict that spanned 27 years. Post-civil war Angola has several challenges that lies ahead; rebuilding its nation and infrastructure, and setting a path towards sustainable development. With its vast array of natural resources and capacity for rehabilitation, there exists much hope in the country's endeavour towards post-conflict reconstruction. This chapter will give a profile of Angola, beginning with a general profile of the country, moving towards an energy-centred focus.

4.2. Geography

Angola is located in Southern Africa, bordering the Atlantic Ocean between Namibia and Democratic Republic of the Congo and is made up of 18 provinces (Figure 4.1.) (CIA, 2007). With a total area of 1 246 700 km^2 and a population of 15,94 million (2006 estimate) it is estimated to be five times the size of the United Kingdom (FAO, 2006; CIA, 2007). The country can be divided into four major physiographic regions (FAO Mapping Information Systems, 2007):

(1) a low lying coastal plain, with a width varying from 25 km in the South to 100 to 200 km in the North

(2) The central highlands or Angolan plateau, covering almost two-thirds of the country (Funk and Wagnalls, 2006). It has an average height between 1000 and 1300 m dominated by several mountain chains. It includes the Serra Moco, the highest point in the country (2620 m). this region is also one of the main sources of water for Southern Africa

(3) The Northern foothills of the highlands toward the Congo basin, where most of the country’s closed forests are found. The remainder of the forests being located in Eastern Cabinda

(4) The Eastern and Southern foothills of the highlands towards the central depression of Southern Africa and the Kalahari basin

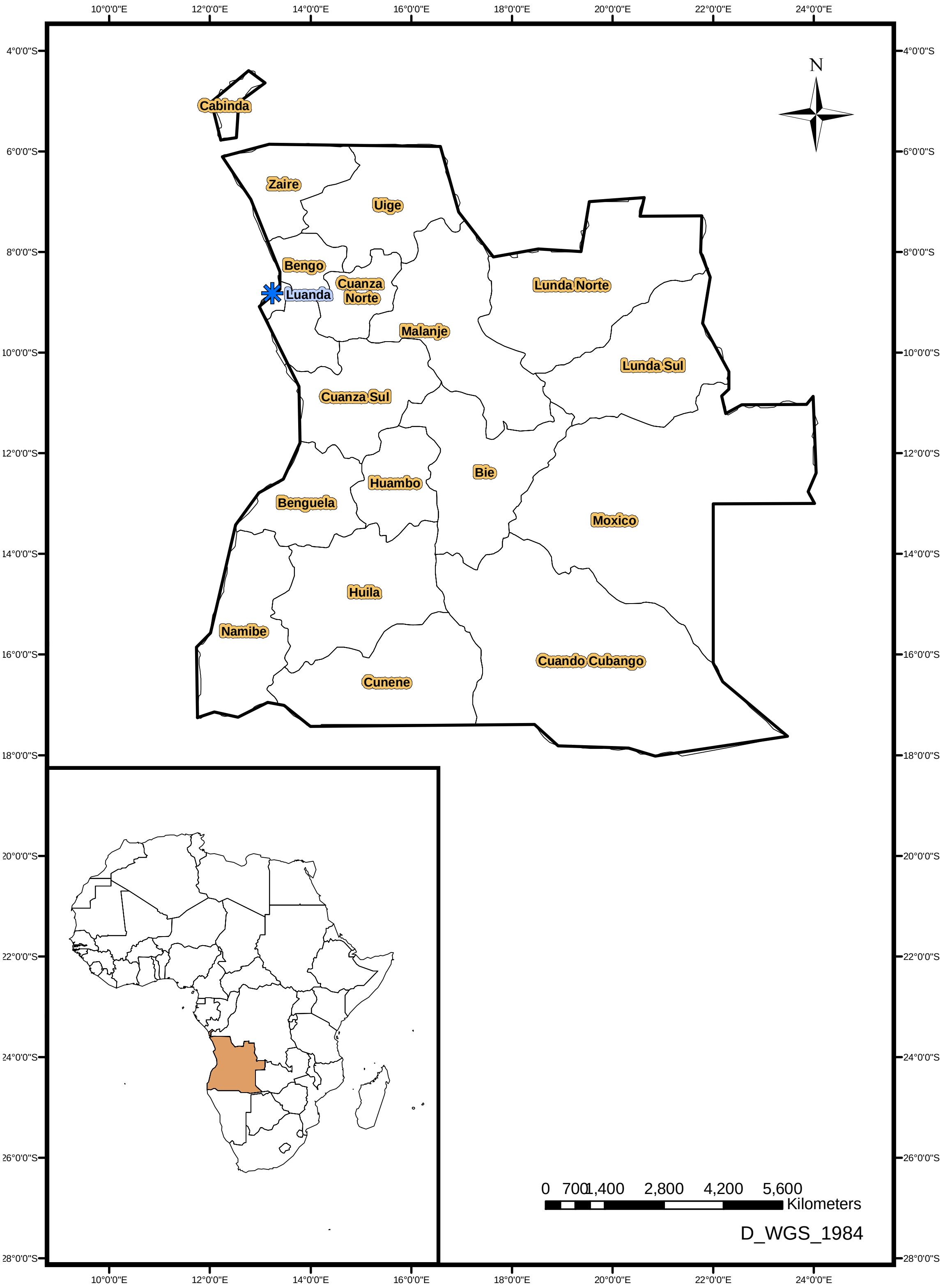

Figure 4.1. Location of Angola in Africa and Angola's provinces

4.3. Climate

Climatic conditions vary widely in Angola, from humid tropical lowlands in the north and northeast to desert on the southern coast bordering Namibia (Kyle, 1997). Angola has a tropical climate with alternating wet and dry seasons, conditions ideal for sugarcane cultivation. The wet, hot season is from November to April, and the dry, cool season is from May to October. Temperature in the coastal region is moderated by the offshore, cool Benguela current which subsequently reduces precipitation. The coastal areas are therefore much dryer with an average annual rainfall of less than 100mm (Kyle, 1997). The highest mean annual rainfall in Angola is seen in the North, approximately 1500mm, but reduces as one moves towards the South to 750mm (Funk and Wagnalls, 2006). The central highlands have large areas with an annual rainfall of 1500-2000mm (Kyle, 1997).

4.4. Vegetation

Extending from the country’s capital, Luanda, to Namibia is a dry coastal strip. Angola has well-watered agricultural highlands, with savanna dominating the far-East and South and dense tropical rain forests are encountered as one moves towards the North and the Cabinda exclave (Nations Online, 2007). There are arid seaward plains between Sumbe and the mouth of the Cunene River (IWMI, 2006). Most of the interior plateau in the south and east of Angola is dominated by savannas of varying density, with closed forests occurring at lower levels in the river valleys tributary to the Zaire River (IWMI, 2006). On the higher valley sides, forests are backed by savannas. In Cabinda, the littoral vegetation is mainly grassy savanna which transitions into dense forests on the low hills. As Angola is one of the wettest countries in Southern Africa, it is well endowed with a variety of wetland vegetation. The interior is characterised by dambos and extensive swamps and marshes, riparian strip swamps occur along some of the major rivers (IWMI, 2006). Strips of tall swampy forests are found along the rivers flowing into the Zaire Basin in North Luanda. Abundant mangroves occur in Cabinda and Cuanza floodplains, Mussulo Restinga, Lucula, Lucunga and M’bridge river-mouths with a total surface area of 700-1250 km^2 (UNEP, 2007). Thus, from the overview provided on Angola’s vegetation, it can be seen that Angola is a country of great ecological diversity.

4.5. Angola's agriculture sector

Angola's agriculture is predominantly a family-labour activity for small-holder subsistence peasants such that 85% of the population is dependent on agricultural production (FAO, 2006; CIA, 2007). In most rural areas, except in the south where livestock predominates, agricultural crop production is the main source of livelihood (FAO, 2006). However, at present Angola is only using 3.6 million hectares of its total land area to grow crops (Johnson and Rosillo-Calle, 2007; Van Den Berg and Rademakers, 2007). This equates to only 2.9% of its total land area, which suggests the considerable scale of available land resources in comparison to the current low levels of land utilisation (Johnson and Rosillo-Calle, 2007). Van Den Berg and Rademakers (2007) further suggest that Angola has 88 million hectares of land that is potentially suitable for agriculture which is equivalent to approximately 71% of the country. However, it is likely that this estimate includes savannas which are inherently unsuitable for cropping and should only be used as rangeland (Watson, 2007; *pers. comm.*).

Angola is a potentially agriculturally rich country, with fertile soils, a favourable climate and a mass of 57.6 million hectares of agricultural land[2] (FAO, 2006; Johnson and Rosillo-Calle, 2007). Its leading subsistence crop is cassava or manioc, with an annual production of 369 000 tons (Funk and Wagnalls, 2006).

There are three main agro-ecological regions in Angola which correspond to the main climatic and geographical features of the country (Kyle, 1997; FAO, 2006; UNEP, 2007):

1. The humid northern region in which cassava, tropical crops (peanuts, palm oil, castor oil), coffee and cotton are predominant
2. The sub-humid central region which is suitable for maize, sisal, sunflower and wheat
3. The semi-arid southern region which is mainly for grazing and the cultivation of sorghum and wheat

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[2] Agricultural areas are those which include temporary and permanent pastures and temporary and permanent crops. They also include grasslands and other areas (Johnson and Rosillo-Calle, 2007).

In the central plateau, potatoes are also an important crop and rice is grown over large areas in the north. Sugarcane is growing in the coastal flats near Luanda (UNEP, 2007). Historically, in Angola the most important cash crop has been coffee which grows in the provinces Uige, Malange, Cuanza Norte and as far south as Humbo and Bie. Other major crops include, corn, sugarcane, sweet potatoes, banana, millet, beans, palm products and sisal, however the major export crop is coffee (Funk and Wagnalls, 2006; CIA, 2007).

4.6. Minerals and Natural Resources

Angola is a country that is rich in minerals and natural resources, with oil being its greatest resource. Oil production and its supporting activities contribute approximately to half its GDP and its sale accounts for 90% of government revenues (CIA, 2007; Clough, 2007). After Nigeria, Angola is sub-Saharan Africa’s second largest producer of oil (Clough, 2007). Proven oil reserves have tripled in the last seven years, and its crude oil production has more than quadrupled over the past twenty years (EIA, 2005; Clough, 2007). From 280 000 barrels of oil per day (bbl/d) in 1986, Angola currently produces on average 1.25 million bbl/d, and in 2008 oil production is expected to rise to an astounding 2 million bbl/d.

However, despite Angola being potentially rich due to oil export revenue, much of this revenue is mortgaged through repayment of earlier oil-backed loans and is not available in the short term (Eggington, 2006). Furthermore, as Angola is rebuilding its infrastructure, there are heavy demands for investment of government funds in various sectors in the country. The energy sector is seen as essential to improving the country’s socio-economic situation, and thus, investments into areas such as bioenergy appears attractive. Specifically, the production of bioethanol from sugarcane is a means of decreasing dependence on foreign exchange earnings, and has enormous potential in making Angola energy self-sufficient. The potential contribution of bioenergy to energy security and socio-economic upliftment has been discussed in Chapter 1, section 1.4.

Diamonds remain the second most important mineral in Angola with earnings from exports making up 7% of government revenue (Clough, 2007). Other important minerals and natural resources include, iron ore, natural gas, phosphates, copper, feldspar, gold, bauxite and uranium (Funk and Wagnalls, 2006; CIA, 2007). Overall, its main mineral exports are crude oil, diamonds, refined petroleum products and gas (CIA, 2007).

4.7. Population characteristics

The majority of the Angolan population is overwhelmingly rural, with only one-third of the population living in urban areas (Funk and Wagnalls, 2006). The country faces extensive unemployment, such that half of the population is unemployed and an estimated 70% of the population lives below the poverty line (less that $2 a day) (CIA, 2007). The total labour force is estimated at 6.3 million of which 85% are engaged in agriculture (2007 estimate) (CIA, 2007). Education in Angola has improved with the government pledging a campaign to drastically reduce the illiteracy rate. Their efforts were reflected by the increase in percentage literacy from a mere 42% in 1990 to 67.4% in 2007 (CIA, 2007). HIV/AIDS is another issue affecting the Angolan population. It is estimated that the HIV prevalence rate is 3.7% and between 200 000 to 450 000 people are living with HIV/AIDS (2007 estimate) (UNAIDS, 2007). However, this is very low compared to other African countries. Angola is considered to have the lowest HIV/AIDS prevalence rate in the Southern African region, for example compared with South Africa which has a prevalence rate of 21.5%, Mozambique (16.2%) and Namibia (21.3%) (FAO, 2006).

4.8. Organisations

Angola is a member of the Southern African Development Community, the Common Market for Eastern and Southern Africa (COMESA) which is a 20 member organisation working to liberalise trade and promote regional integration and the African Union (Clough, 2007). In addition, on 1 January 2007, Angola became the twelfth member of the Organisation of Petroleum Exporting Countries (EIA, 2007).

4.9. Environmental Agreements and Environmental Overview

Angola is party to Biodiversity, Climate Change, Desertification, Law of the Sea, Marine Dumping, Ozone Layer Protection, Ship Pollution (signed, but not ratified) (CIA, 2007;

EIA, 2007). Annually, it emits 19.7 million metric tons of carbon dioxide, of which oil contributes 35% and natural gas contributing 7% (EIA, 2007). Angola faces several environmental issues such as deforestation of its tropical rainforests in response to both international demand for timber and domestic demand as use for fuel. Between 1990 and 2000, Angola has lost approximately 2% of its total forest area (WRI, 2003). Other environmental issues include, desertification, soil erosion contributing to water pollution and siltation of rivers and inadequate supplies of potable water (EIA, 2007).

The SADC has a biofuels initiative which is line with its Regional Indicative Strategic Plan (RISDP) (Takavarasha *et al.*, 2005). As Angola is a member of SADC, such an initiative is an encouraging means of support to biofuels implementation in the country. More comprehensive biofuel policies are underway in the SADC region through revision of current energy policies and strategy to include the biofuels sector.

4.10. Angola's Power Industry

Only 15% of Angola's population has access to electric power, however, this may not be a reliable supply of power as blackouts occur frequently. As a result, energy security is a major concern for the country. The country's electricity generating capacity as of 2003 was 0.7 gigawatts, which is split between thermal (oil and gas-fired) and hydroelectric units. However, hydroelectric facilities generate more than two-thirds of the country's electricity (EIA, 2007). Angola's electricity generation during 2003 was 1.9 billion kilowatt-hours with consumption being 1.8 billion kilowatt-hours (EIA, 2007).

Three separate systems are used to supply electricity throughout the country (Clough, 2007):

(1) Northern System which supplies the provinces Luanda, Bengo, Cuanza Norte, Malange and Cuanza Sul
(2) Central System which supplies the provinces of Benguela, Huambo and parts of Bie
(3) Southern System which supplies to Huila and Namibe provinces

The government, however, aims to link these three systems to create a national grid through the South African Power Pool (SAPP).

As mentioned, the country’s major electricity producers are hydroelectric facilities, however, as a result of the civil war, out of the six facilities only three are functional. The Matala Dam on the Cunene River is the main source of electricity in south-west Angola, with Northern Angola receiving electricity from the Cambambe dam on the Kwanza River, the Mabubas Dam on the Dande River and diesel generators (Clough, 2007). In addition, in north-east Angola, a 24-MW dam is being built on the Tchicapa River (Clough, 2007). A Brazilian construction company, Odebrecht, has partially completed an additional hydroelectric facility at Capanda on the Kwanza River which could nearly double Angola’s electricity generating capacity.

By further rehabilitating the country’s hydropower stations, Angola intends to restore the productive capacity of its state-owned electric utility, Empresa Nacional de Electricidade (ENE). In November 2003, together with the national utilities of five countries, BPC (Botswana), Eskom (South Africa), NamPower (Namibia) and SNEL (DRC), Angola’s ENE formed the Westcor Power Project to provide low-cost and environmentally friendly electricity to ensure the economic development of the region (EIA, 2005).

4.11. Transport - road, rail and the agricultural sector

Road or rail transport is a means of delivering goods and supplies to the agricultural area as well as delivering agricultural products to the processing phase, which may be located a distance away from the agricultural phase. Furthermore accessibility to roads is a means of facilitating marketing of agricultural produce, which is especially relevant in Angola. A 2006 special report on the crop and food supply situation in Angola produced by the FAO has made extensive acknowledgement of the poor condition of Angola’s road network. Consequently, the poor conditions have had several implications for food security for some of Angola’s provinces. For example, even though the marketing and market situation in Angola has improved over the last four years, hindering its proper functioning are serious infrastructural impediments characterised chiefly by the poor condition of roads and transport. In 2006, it was possible to achieve good yield of potatoes in the Planalto central (central region) but due to poor transport infrastructure, by the time the produce gets to Luanda, it cannot compete in terms of price with imported potatoes from Brazil (FAO, 2006). In Malanje, located in northern Angola, the condition of the roads posed a major constraint to the movement of commodities from production areas to markets (FAO, 2006). In contrast, in some regions, good road conditions has been a driving force for the acceptable movement of commodities from the production areas to the markets. This is the case noted in Cuanza Sul, located in the central region of Angola, in which the prices of maize, beans, groundnuts and cassava are low and affordable to the majority of households. Some of the best roads in the country are located in Namibe (southern region) which facilitates exceptional marketing of produce from small-scale commercial riverside cultivation.

The are three main railroads in Angola (appendix) (SARA, 2003),

1. Benguela railway running from the Benguela province which is an essential lifeline for commercialisation (SARA, 2003).
2. Luanda railway located in Luanda province
3. Mocamedes located in Lubango in the Huila province

Needless to say both road and rail infrastructure in Angola have been damaged by the nearly three decades of civil war. As a result, Anglola's Transportation Policy Strategies ranks investments in road and rail infrastructure high among the list of investment priorities (Kuvingua, 2004). In 2006, it was reported that a US$4 billion program, backed by Chinese loans, to repair road and rail infrastructure had been completed (Esipisu, 2006). In addition, in 2006, Angola launched the next phase of rail refurbishment and in some cases building of new sections to open transport routes to the Congo, Zambia, Zimbabwe and Botswana (Esipisu, 2006).

4.12. Irrigation and irrigation potential

As this study is concerned with irrigated agriculture in Angola, specifically the cultivation of sugarcane, an overview of the irrigation scenario in the country would prove useful in understanding its potential for irrigation as well as the several challenges it faces. Angola has a vast network of permanent rivers flowing through the country which offers enormous opportunities for irrigation (FAO, 2006). Many farmers living close to streams make use of these water sources for supplementary irrigation, however there is a great shortage of structure irrigation works in the country. According to 2003 data, the overall potential area for irrigation was estimated at 6.7 million hectares of which 3.7 million hectares are potentially covered by small irrigation schemes and lowland irrigation (NEPAD-FAO, 2005). In 2004, the total effectively land irrigated was estimated to be 64 750 hectares.

According to 2005 data, there are three main types of irrigation systems co-existing in the country (NEPAD-FAO, 2005).

1. ***Large to medium scale irrigation systems fully or partly equipped with water control works*** (approximately 100 000 hectares of land irrigated this way)

- Occupy various river floodplains in the humid and dry coastal zone and in the southern temperate zones
- Used in the production of the country's cash crops which includes sugarcane
- Initial projects were set up in Luanda, Bengo, Benguela, Namibe, Cuanza Sul and Huila but new projects have been established extending to Cunene, Malanje and Moxico
- Supports large to medium-scale farmers with plots varying from 15 to 50 hectares, and small-scale farmers with plots of 3 to 4 hectares

2. ***Small-scale gravity or pumped systems***

- Represents most important part of national irrigated area and is found in the central Plateau covering Huambo and Bie
- Used to produce maize, vegetables and fruits
- Supports small-holder commercial farmers

3. ***Lowlands and depressions utilising water conservation farming practices***

- Found in vast areas in central and east Angola where rains are sufficient but unequally distributed
- Limited amounts of vegetables are produced in these areas

Due to the several years of conflict, existing irrigation systems and the installation of new systems were neglected. Thus, in order to ensure and promote development of the country's social and economic infrastructures, the Government of Angola aims to rehabilitate the country's irrigation systems. Rehabilitation is expected to play a critical role in attaining food security in the short- to medium-term (NEPAD-FAO, 2005). This, essentially, would underpin revival and expansion of Angola's agricultural sector. Further advantages are envisioned for the long-term which includes increased incomes for small-holder and commercial farmers since the same land would be cropped more than once annually. Commercial farmers could further benefit by having an opportunity to offer contracted services such as operation maintenance of irrigation equipment and combined harvesting. Reduction in poverty, job creation for farm labour and availability of more food staples are seen as added advantages to the rehabilitation of the country's irrigation systems (NEPAD-FAO, 2005).

4.13. Conclusion

With its enormous resource of oil, natural gas and diamonds and the availability of agricultural land and adequate rainfall, Angola is potentially a wealthy country. However, it still remains one of the poorest countries in the world, reflecting the heavy toll of colonialism and 27 years of civil war. Performance outside the minerals sector has not yet achieved its full potential due to the lack of institutional capacity and the challenging business environment, and as a result has left most Angolans without a sustainable income (World Bank, 2006). Its has been suggested that in order for Angola to take full advantage of its natural resources, it would have to implement government reforms and reduce corruption (CIA, 2007). However, the introduction of cleaner forms of energy, such as bioethanol or bagasse-cogenerated electricity is another promising endeavour to promote income-generating activities. At a 2001 meeting at the Commission on

Sustainable Development, cleaner energy was seen as the key to improving the welfare of the people and the standard of living, without environmental degradation. Bioenergy programs have the potential to take Angola to its full potential, by making use of the vast amounts of available non-forested agricultural land. The country has the capacity to meet the food, feed and fuel requirements of its growing population and will still have adequate land available for bioenergy implementation (Van Den Berg and Rademakers, 2007). This capacity projects Angola to be the world's next biofuel superpower, with the potential for social, economic and environmental upliftment.

Therefore, currently, Angola shows the greatest potential in assisting the world to meet its energy requirements. As fossil fuel resources are finite and is fast becoming depleted, the world is turning towards sources of renewable energy. Angola, therefore, makes Africa's future sustainable bioenergy production so large, and with bioenergy, the country's export potential in 2050 is estimated to be around 6 exajoules per year, the equivalent of 2.7 million barrels of oil per day. In addition to facilitating the world's energy needs, renewable energy resources is also imperative to meeting Angola's energy needs, as oil demand and consumption is projected to increase as infrastructure is refurbished and expanded (Clough, 2007). Furthermore, with only 15% of the country having access to electric power, electricity generated from bioenergy (electricity cogeneration), is a further incentive for bioenergy implementation.

Chapter 5

Methodology

5.1. Introduction

The previous sections provided the background that forms the theoretical framework that underlies this study as well as a description of the study area. This chapter will provide an overview of the methodological approach taken in this study to identify suitable areas for sugarcane cultivation, the tools used to evaluate the study area for suitability as well as the steps taken to produce the results.

5.2. Methodological Approach – A Land Suitability Assessment

As population numbers are steadily increasing so is the demand placed upon food and fuel. This increasing demand places pressure on land availability, leading to intensive grazing and cropping of land in areas which are less suited to such uses and which are also ecologically more fragile (FAO, n.d.). Therefore, in order to preserve Earth's natural resources and sustainably provide food and fuel, land use planning becomes critical. The landmark FAO (1976) publication, *A Framework for Land Evaluation*, asserts that land suitability assessments or land suitability evaluations constitutes a crucial aspect of land use planning, by assessing the fitness of a given type of land for a specific use. The framework was developed to assess potentialities as well as limits of the world's land resources for development, and for the past 30 years has served as the internationally accepted methodology for land evaluation (FAO, 2007). Initial land evaluations were primarily carried out for land use planning and land development projects, however, as the scope and purpose of land evaluations have changed during the past 30 years, the FAO (2007) suggests a revision of the original framework. Land evaluations have evolved to solving conflicting demands on limited land resources and requires more participatory methods to be used in agricultural development.

The 2007 suggested revision of the original framework still shares the basic principles of the 1976 publication. Of these, the framework asserts that land evaluations should take into account the biophysical, economic, social and political context as well as the environmental concerns associated with evaluating a land area for a specific land use (FAO, 1976; FAO, 2007). The current study drew from the principles outlined in the 1976 publication and the modifications of the suggested revised framework. Specifically, the approach taken in this study involved assessing the study area using biophysical parameters to establish its suitability for sugarcane cultivation. This produced a series of maps that were discussed in a broad socio-economic context.

Land evaluations may be conducted in either physical or economic terms, with physical evaluations assessing the suitability of a land using physical (biophysical) characteristics such as soil type, rainfall and water availability (FAO, 2007). In the original framework, such evaluations were referred to as qualitative, however this is a misnomer because many physical land evaluations are actually carried out in quantitative terms such as the Agro-ecological zoning methodology, which is used to define suitability, production potential and environmental impacts of a land to a particular land use (FAO, 2007). As such this study is a quantitative evaluation, which involves filtering out protected areas, analysing land cover classes, calculating proximity to roads, railroads and rivers as well as filtering out steep slopes. However, the study also included a few qualitative judgments, by selecting major areas suitable for sugarcane cultivation based on purposively selected criteria.

As it was beyond the scope of the study, an economic land evaluation which involves precise calculations of the economic costs and returns of the area placed under cultivation was not carried out. Furthermore, the intensity of the study is concerned with a broad inventory of natural resources at the national and regional level (FAO, 1976).

5.3. Intended land use

According to the FAO (1976), a suitability evaluation involves relating land mapping units to specific types of land use. Therefore, in a land suitability assessment it is critical to define the use that is intended for that land. Two major types of land use have been outlined (FAO, 1976):

(1) A major kind of land use, which is a major subdivision of rural land use such as rainfed or irrigated agriculture. This type of land use is usually considered in qualitative land evaluation studies at the reconnaissance level.

(2) A land utilisation type, which is a kind of land use defined in a degree of detail greater than (1). It is usually used in quantitative land evaluation studies and are described in much detail and precision as the purpose of study requires. It consists of a list of technical specifications in a given physical, social and economic setting. It takes into consideration if the current environment would be modified, e.g. by irrigation schemes or is intended to remain in the present condition. Examples of land utilisation types includes, market orientation (either commercial or small-scale production), labour intensity and infrastructure requirements.

Further to this description, the intended use for the land in this study appears to fall somewhere between the two classifications. The intended use of the land is at a commercial production level considering irrigated agriculture. The consideration includes infrastructure requirements, however it does not include labour intensity as such, but rather an analysis of population data for an indication of available workforce.

5.4. Overview of methodology

This study employed the techniques of Geographic Information Systems (GIS) and Remote Sensing (RS) to evaluate land for the purpose of sugarcane cultivation for bioenergy. The project took an evolutionary approach to the methodology, whereby the methodological procedure was continuously developed and refined throughout the course of the project. The initial step in the methodology was the identification of areas suitable for sugarcane cultivation in the study area. This was achieved by using remotely sensed data which identified areas suitable for sugarcane cultivation based on the spectral signature of sugarcane in the electromagnetic spectrum. However, the dataset does not consider current land use and protected areas, and therefore additional datasets including global land cover and protected areas had to be overlain with the initial dataset to filter out overlapping areas. Areas that were filtered out were, protected areas, croplands indicating areas currently under cultivation, as well as areas which would prove biologically and agriculturally unsuitable for cane growth such as salt hardpans and mangroves. For a complete list of filtered land cover classes, the reader is referred to Chapter 6, section 6.3.

The remaining areas were then analysed in a broad socio-economic context using population characteristics and proximity to transport infrastructure (road and rail). This step gave an indication of the viability of establishing an area for sugarcane cultivation, as transport infrastructure is an indication of land quality (FAO, 2007). An efficient transport network is essential for transporting cultivated cane to the mill, as well as transporting farming goods and agricultural produce into and out of the cultivated area. Population data is an indication of the workforce available to the selected agricultural areas.

As the study is based on identifying suitable areas for irrigated agriculture, the identification of water sources, was essential. Irrigated agriculture is gaining an increasing importance especially in the light of global climate change where rainfall patterns are predicted to decrease and become erratic (Hulme *et al*., 2001). Thus, irrigation would prove a more reliable means of meeting crop water requirements. However, prior to considering irrigated agriculture, factors such as slope, soil type and distance to water source require consideration. These factors will influence the cost and type of irrigation system installed and hence have a bearing on the overall value of the irrigated land (Dumler and Rogers, 2006; Lecler, 2007; *pers. comm.*). More specifically, the factors to consider when deciding on an irrigation system are (Dumler and Rogers, 2006):

- Available capital
- Available labour during the growing season
- Well capacity
- Topography of the field
- Soil type
- Pumping cost, and

- In which type of irrigation system do management expertise have the most knowledge and experience

However, this study does not provide an inventory of the economics associated with irrigation and thus, only considers distance to water sources (which has implications for pumping costs) and topography of the field in terms of percent slope. Dr. Neil Lecler, a senior research engineer at the South African Sugar Research Institute (2007, *pers. comm.*) suggested that these calculations would best assist a stake-holder in deciding what are the constraints and costs as per their specific circumstances. There is no definite threshold (in terms of distance to water source and slope) at which irrigation is either 'feasible' or 'not feasible', rather it is up to a stake-holder's specific circumstances that decides on the constraints to irrigation (Lecler, 2007; *pers. comm.*)

5.5. Tools for Evaluation

5.5.1. Geographic Information Systems

Geographic information systems (GIS) is a technological framework that enables analysis and manipulation of spatial data. It can provide information on relationships and trends between spatial features in a geographic area. GIS is therefore defined as a "computer-based system for the capture, storage, retrieval, analysis and display of spatial data" (Skidmore, 2002). Its spatial analytical capabilities makes it a convenient tool for land suitability analysis, presenting results in the form of maps and reports which can be meaningful to a local user (Boonyanuphap *et al*., 2004). GIS proves useful in meeting the objectives of a land suitability assessment, such as constructing geographical databases for land suitability, assessing land suitability as well as the selection of new areas for crop plantations. For these reasons several land suitability studies have employed GIS as the main data processing and analytical tool (Schulze *et al*., 1997; Ghaffari *et al*., 2000; Bezuidenhout and Gers, 2002; Rasheed *et al*., 2003; Boonyanuphap *et al*., 2004; FAO, 2004a).

In this study, the GIS software used was ESRI® ArcMap™ (version 9.2). It provides a multitude of analytical procedures, with the ability to process and display both raster and vector datasets successfully. Remotely sensed data such as land cover maps, and Digital Elevation Models (DEM) are examples of raster datasets, which are characterised by grid cells of uniform size. On the other hand, vector datasets include point, line or polygon features such as population nodes, rivers, and land parcels.

5.5.2. Remote Sensing

Remote sensing is collectively referred to as the collection and interpretation of information about an object or area without being in physical contact with that object (Campbell, 1996; Sanderson, 2003). This involves the use of platforms such as aircrafts and satellites utilising different portions of the electromagnetic (EM) spectrum to gather information about the natural environment. The physical basis underlying remote sensing is concerned with the EM spectrum and the way in which emitted illumination interacts with the surface of objects. Therefore, the central hypothesis of remote sensing is that radiation reflected from a surface of an object carries information about that object and the state of its surface (Myneni *et al.*, 1995). The reflectance of radiation from different objects varies over the range of wavelengths in the EM spectrum which helps in differentiating between land covers, e.g. soil, water and vegetation (Sanderson, 2003). Different surface materials reflect radiation differently and this is referred to as the spectral signature of the object. Therefore, a material can be identified by its unique spectral response in the EM spectrum. Vegetation for example, can be distinguished from other land cover types due to its characteristically high reflectance in the near infrared region and much lower reflectance in the visible region of the EM spectrum. In addition, there exists a difference in reflectance in the near infrared and visible region between vegetation types, which is exploited in vegetation or crop identification.

This study utilises this feature of remote sensing in identifying areas suitable for sugarcane cultivation as well as assessing land cover types in the study area.

5.6. Assumptions and limitations regarding the data and project

It is imperative to provide a list of assumptions regarding the project, as these inevitably influenced the way in which the results were interpreted. Data limitations are also included so as to highlight concerns with the data used in the project.

1. Railroads - It is assumed in this study, that railroads within each site could be dedicated to loading agricultural produce and processed material (including ethanol). Specifically, trains may stop at designated points at a distance from the agricultural area to load sugarcane and other by-products. Use of the rail line could be shared between transporting passengers or for other uses perhaps once or twice a week passing through the selected areas, with the remainder of the week dedicated to transporting sugarcane and its by-products. Similar situations pertain to the uMfolozi flats and Felixton (Watson, 2007; *pers. comm.*) and thus, such an assumption may prove practical.
2. Existing sugarcane farms – The precise geographic locations of existing sugarcane farms in the study area are not known. It is assumed that existing farms are included in the cropland fraction of the GLC 2000 land cover database and as noted in section 5.4. were filtered out. Makenete (2007), estimated that 9 500 hectares of land were under sugarcane cultivation in the country in 2004.
3. The factor of climate change has not been explicitly addressed in this study, thus it is assumed that the areas identified as suitable for sugarcane cultivation pertain to current climatic scenarios.
4. As it was beyond the scope of the project, land tenure and land reform have not been addressed.
5. Land mines – During the civil war landmines restricted agriculture in certain areas. They impose a constraint on the expansion of cropped area, such as in Bimbi in Huambo (FAO, 2006). However, the FAO (2006) reports that there has been a continuing clearing of landmines, which has led to the slight expansion of cropped area. Areas with landmines have not been addressed in this study and thus, it is assumed that landmines are not an issue in the selected areas. This may be a very

naïve assumption, however due to the lack of such data it is not feasible to factor this into the land suitability assessment.

6. Legislation concerning water use for irrigation has not been dealt with. However, it is known that notwithstanding the *Land Law* and *Water Law*, no specific policy, law or legislation has been drafted for the field of irrigation; as per 2005 data (NEPAD-FAO, 2005).
7. Reliability of data
   - GLC 2000 - It is acknowledged that all data carries a level of uncertainty. For example, the study area is noted for its abundant mangroves in Cabinda and Cuanza floodplains, Mussulo Restinga, Lucula, Lucunga and M'bridge river-mouths with a total surface area of 700-1250 km^2 (UNEP, 2007). However, this vast expanse of mangroves was not identified in the GLC 2000 dataset. It is likely that the mangroves were not shown by the GLC 2000 because they are not a dominant surface in the pixel distribution, as they may occupy a long narrow strip rather than dense broad areas. It is possible that the final assessment of suitable areas may overlap with mangroves, and the necessity of a site visit becomes essential in verifying the accuracy of the resulting suitable areas. The resolution of the GLC 2000 dataset is 1 km^2, which may be considered as coarse, and thus, narrow strips of mangroves or vegetation are likely to feature in datasets of higher resolution. However, as this study was conducted on a broad level with the study area spanning the whole of Angola, coarse resolution imagery was considered as more than sufficient in narrowing down Angola's vast expanse of agricultural land to areas that are suitable for sugarcane cultivation.

   - Protected areas - Following perusal of the protected area site details in Angola using the UNEP-WCMC world database on protected areas website (http://sea.unep-wcmc.org/wdpa), a few discrepancies became apparent in the WDPA 2006 database. The site details listed on the website are a 2007 update and identify an additional three protected areas in Angola which are not listed and shown in the WDPA 2006 database. These include the Namibe Partial Reserve, Mucosso Hunting Reserve and the Illheu dos Passaros Integral Nature Reserve which collectively adds a further 29 606 km^2 to the national protected areas. It is likely that these areas will be included in the WDPA 2007 database. However, all analyses and calculations have been made according to the protected areas listed in the WDPA 2006 database.

5.7. Data sources

All datasets used in this study were in digital format and are available in the public domain with the exception of the ESRI® Data & Maps 2006 media kit. It is imperative to note that high resolution and accurate data for the African continent is difficult to obtain, however, as this study analyses suitability across the Angolan country, data of 1 km^2 is considered adequate. Such resolution may not be considered as high, however when assessing suitability on a broad scale such as county level, coarse resolution data is adequate. In general, the accuracy and precision of results most definitely varies with the quality of data. In comparison to previous studies (Schulze *et al*., 1997; FAO, 2004a) the data used in this study affords a higher level of confidence in the accuracy of the results obtained. Specifically, resolution of data used by Shulze *et al*., (1997) in identifying areas climatically suitable for sugarcane cultivation in South Africa was 2 km^2, whilst the FAO (2004a) used much coarser resolution data (10 km^2) which makes it difficult to pinpoint areas suitable for sugarcane expansion as each pixel of the dataset represents an area of 10 km^2. As such, comparatively, the data used in the present study is considered as sufficient. Furthermore, considering the datasets available in the public domain, the GLC 2000 dataset is undoubtedly the best option.

5.7.1. Land cover

Sustainable land management requires an assessment of the current land cover of the area of interest and as such land cover information becomes an essential tool for development planning and management of the territory (FAO, 2002a). It gives an indication of the current coverage of a particular area, and in addition to the types of vegetation that may cover a certain area, land cover types such as cities, water bodies and built up areas are also included. Sustainable land management is made possible by land cover information by avoiding the cultivation or development in areas which are already under use for a specific purpose or are of biological and ecological significance.

Remote sensing provides the most cost-effective and accurate means to obtain global land cover information. In addition, satellite remote sensing records information in various wavelengths which provides accurate information on ground conditions (FAO, 2002a). Two land cover databases were used in this study to identify potentially suitable areas for sugarcane cultivation as well as to remove areas of overlap between suitable areas for sugarcane cultivation and specific land cover types (areas which are agriculturally unsuitable and unavailable for sugarcane cultivation). The *International Geosphere Biosphere Programme (IGBP) 1 km*^{2} *Land Cover Product (1997)* raster land cover dataset was produced by the U.S. Geological Survey's (USGS) Earth Resources Observation System (EROS) Data Centre, the Joint Research Centre of the European Commission (JRC) and the University of Nebraska-Lincoln. Data was derived from 1km^2 Advanced Very High Resolution Radiometer (AVHRR) with a temporal resolution spanning a twelve month period (April 1992-March 1993) to delineate seasonal land cover regions (SLCR) for the African continent. The database forms part of the MIOMBO network (1996) which aimed at compiling data from the international and regional communities and making them available to the regional community at large. In order to delineate seasonal land cover regions, the MIOMBO network conducted a multitemporal unsupervised classification of NDVI (normalised difference vegetation index). This classification was used to identify natural groupings of pixels with similar NDVI properties. The NDVI is a vegetation index using the characteristic high reflectance of vegetation in the near-infrared region of EM spectrum and low reflectance in the red region (Sanderson, 2003). The IGPB database provided the starting point of this project by indicating areas that are potentially suitable for sugarcane cultivation.

A previous study conducted by Baijnath (2005) examined the extent to which the MIOMBO dataset accurately represented existing sugarcane cultivated areas. The MIOMBO dataset was overlain with the Bezuidenhout and Gers (2002) and Schulze *et al.*, (1997) datasets to examine how accurately it represented existing sugarcane cultivated in South Africa. Following this analysis, it was found that with the exception of a few additional areas near Tzaneen, Volksrust, Louis Trichardt and Ermelo; the MIOMBO dataset overlapped with the datasets. The analysis resulted in an 88% correlation between the MIOMBO dataset and areas where sugarcane is currently grown in South Africa. By using the example of South Africa it was assumed that other areas identified in the MIOMBO dataset were also potentially suitable for sugarcane cultivation. Baijnath (2005) further interrogated the areas represented by the MIOMBO dataset by using climatic, rainfall and soils data, as well as altitude. This was done for the countries Malawi, Mozambique, Tanzania and Zambia, and based on these biophysical characteristics it was verified that the areas identified as potentially suitable for sugarcane cultivation by the MIOMBO dataset were indeed suitable.

Following Baijnath's (2005) verification, it was not necessary in this study to further analyse the potentially suitable areas (identified by the MIOMBO dataset) in terms of climate, rainfall and soil data.

The Global Land Cover Project 2000 (GLC 2000) was used to remove areas of overlap between suitable areas (SLCR) and specific land cover types. The land cover classification was produced by the Global Vegetation Monitoring Unit of the European Commission Joint Research Centre for the year 2000 at a spatial resolution of 1 km^2. The aim of the project was to provide accurate baseline land cover information to the International Conventions on Climate Change, the Convention to Combat Desertification, the Ramsar Convention and the Kyoto Protocol. Data was recorded using the vegetation sensor on board the SPOT4 satellite, and was classified using the Land Cover Classification System (LCCS) produced by the FAO (Di Gregorio and Jansen, 2000). The GLC 2000 dataset was supplemented by the Global Built-up Areas (2006) dataset, which is a set of vector polygons delineating urban sprawls of the major cities and towns of the world.

5.7.2. Protected areas

The IUCN definition of a protected area developed at the IVth World Congress on National Parks and Protected Areas in 1992 is:

"An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means." (UNEP-WCMC, 2006).

Identifying protected areas is seen as a major tool in protecting biodiversity and conserving species and ecosystems as they provide a range of goods and services which are essential to the sustainable use of natural resources (UNEP-WCMC, 2006). Information on protected areas is therefore crucial in enabling a wide range of conservation and development activities (UNEP-WCMC, 2006). There is wide variation in the types of protected areas and degree of protection, often influenced by a country's national needs and priorities. Sites may be protected on an international level recognised by international conventions or agreements such as Biosphere Reserves, RAMSAR and World Heritage Sites (UNEP-WCMC, 2006). Sites may also be protected at the national level, which maybe uncategorised, or categorised using the six protected area IUCN management categories (I-VI) which identifies strict nature reserves, wilderness areas, national parks, natural monuments, Habitat or Species Management Areas, Protected Landscape or Seascape Managed Resource Protected Areas (UNEP-WCMC, 2006). Uncategorised protected areas at the National level are those areas which are not assigned IUCN classification and a designated status, and may include those areas which are being proposed for protection or areas with incomplete or inaccurate information (WDPA, 2006). Protected areas without categories does in no way reduce the importance of those areas (Chape *et al*., 2003).

This study used the 2006 World Database on Protected Areas released at the 8th Conference of the Parties to the Convention on Biological Diversity (CBD) in March 2006. It is a vector dataset provided as a set of GIS layers with a nominal scale of 1:1 000 000 with various national scales. It is the most recent documentation of protected areas and according to UNEP-WCMC (2006), it is “the most complete compilation of protected areas data available”.

5.7.3. Roads, Railroads and Rivers

The roads and railroads polyline vector datasets were obtained from the BioGeomancer Project (2005-2007) which is a worldwide collaboration of natural history and geospatial experts. The primary goal of the project is to “maximize the quality and quantity of biodiversity data that can be mapped in support of scientific research, planning, conservation, and management” (http://www.biogeomancer.org/).

The rivers, polyline vector dataset was obtained from the GIS Library of the Southern African Humanitarian Information Management (2003-2005). Specifically, contribution to the Angolan dataset was made by The Angolan Demining Unit and UNDP-CNIDAH (National Inter-Sectoral Commission for Demining and Humanitarian Assistance).

5.7.4. Digital Elevation Model (DEM) and Population data

Elevation and population data was obtained from The ESRI® Data & Maps 2006 media kit which is a set of data available with ESRI® ArcGIS 9.2. Elevation data is represented as a 30 Arc seconds global DEM (GTOPO30) developed by the United States Geological Survey Earth Resources Observation System (EROS) Data Centre in 1996. It has a spatial resolution of 1 km^2. Population data is represented by a State-Province layer and is a symbolized and labeled display presentation of the World administrative units data set.

5.8. Steps in methodology

The methodology followed in this study was largely GIS-based. In order to impart a systematic assessment of all datasets, the methodology followed a three phase process as shown in Figure 5.1.

5.8.1 Phase I

Following the acquisition of relevant datasets, the initial phase entailed the selection and overlaying of specific land cover types. By use of the raster calculator, a feature of the *Spatial Analyst* extension, pixels corresponding to the spectral signature of sugarcane

(SLCR pixels) were selected from the IGBP 1km^2 Land Cover Product dataset. The result formed the basis of the analysis upon which further datasets were overlain and filtered against. Similarly, specific land cover types were selected from the GLC 2000 land cover dataset which included bare rock, cities, closed deciduous forest, cropland > 50%, irrigated crops, tree crops, evergreen lowland forest and waterbodies. The land cover types, global built-up areas and the SLCR pixels were overlain and areas of overlap were removed from the distribution of SLCR pixels. The remaining SLCR pixels were then overlain with the WDPA 2006 protected areas vector dataset. By means of the '*select by location'* and '*Data management*' tools, SLCR pixels that overlapped with the protected areas layer were subsequently removed. This ensured that the remaining distribution of SLCR pixels which fell within unsuitable, unavailable and protected areas were removed and not included in any further analysis. A further selection process was conducted by filtering out SLCR pixels which were located in areas with slopes greater than 16%. This was achieved by using the *Spatial Analyst* extension of ArcMap™. The remaining distribution of SLCR pixels from Phase I was subject to reselection in Phase II.

5.8.2 Phase II

This phase constituted reselection of SLCR pixels using non-biophysical factors. Phase II resulted in the selection of three suitable regions within the study area which was selected by overlaying the roads with the SLCR pixels. Using a purposive[3] sampling method, pixels which were in close proximity to primary roads and areas greater than 10 000 hectares were selected as suitable. Primary roads were chosen due to the infrastructural capacity it offers to transport goods into and out of the suitable area to major cities. Intraplantation transport would make use of the secondary and tertiary roads, which is well distributed in Angola (c.f. Appendix B). The choice of primary roads affords an area the option of using either intraplantation or inter-area transport. As it is not the aim of the project to determine which transportation scenario is most cost-effective and practical for

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[3] Purposive sampling, is a sampling method used to select subjects or areas based on some characteristic, i.e. sampling with a predefined purpose (Patton, 1990). This sampling method is popular in qualitative research, and is categorised by various types. One type of purposive sampling, which is employed in this study, is criterion purposive sampling which selects samples based on some criterion (Patton, 1990). In this study proximity to roads and areas greater than 10 000 hectares were the criteria in selecting areas suitable for sugarcane cultivation, that would prove most viable.

the selected areas, areas are given an option of using either scenario, hence the criterion of proximity to primary roads. The threshold area of at least 10 000 hectares is seen as most feasible for establishing sugarcane farms on a commercial level (Watson, 2007; *pers. comm.*). Pixels falling outside these criteria were excluded from any further consideration.

5.8.3 Phase III

The resulting distribution of SLCR pixels from Phase II were analysed in a broad socio-economic context. This was achieved by inspecting the three selected areas in terms of distance to roads, railroads and rivers. Additionally, the overall topography was assessed by calculating slope (in percentage) from the DEM using the *Spatial Analyst* extension. The distance of each point to the roads, railroads and rivers was calculated by means of a spatial join between the SLCR points and the target layers. By using this function, each pixel was given all the attributes of the point in the target layer being joined that is closest to it, i.e. the distance from each point was calculated to the nearest road, railroad and river. Prior to the analysis, the raster SLCR pixels were converted to vector points, purely for simplicity of analysis.

The final step in Phase III involved interrogation of population information of each of the selected areas. This constituted the social context surrounding each of the selected areas and gave an indication of the potential work force available to the selected areas.

5.9. Verification of areas suitable for sugarcane cultivation using Google Earth®

The author of the present study, commissioned a study using Google Earth®, to verify the suitability of the areas identified as potentially suitable for sugarcane, by the MIOMBO dataset, in the study area. Google Earth®, a product of Google®, is a virtual globe GIS program that combines satellite imagery, maps and 3D flights through cities and several tourists locations (Schele, 2007). The level of detail viewed using this application is considered to be at street level, thus, it is possible to view individual settlements, areas under agriculture and forested areas (http://earth.google.com). However, an inherent limitation of the application is the subjectivity which the analyst has to impose in order to interpret the images. For example, it is possible to view land that is under agriculture, but it is not possible to distinguish between vegetation types (Schele, 2007).

Schele (2007) used 130 180 hectares from the MIOMBO dataset, representing land that is suitable for sugarcane cultivation in Angola. This distribution had already undergone a series of filtering steps using protected areas and GLC 2000. Thus, these areas were identified by the author of the present study as being suitable for sugarcane cultivation without environmental constraints. Of these areas, 90 pixels (9000 hectares) were randomly selected and analysed using Google Earth®. Results from Schele's (2007) study show that several 'suitable areas' are in fact located directly on what appears to be human habitation. Findings indicate that out of a total of 130 180 hectares of land as identified as suitable for sugarcane cultivation, only 65 580 hectares did not fall on inhabited areas and was thus considered as most suitable for sugarcane cultivation. Results from the study conducted by Schele (2007) undoubtedly emphasise the importance of high resolution data and field verification of the suggested areas. Nonetheless, areas identified as suitable using the methodology outlined above served to effectively narrow down Angola's vast expanse of agricultural land to areas which would be most suitable for sugarcane cultivation.

5.10. Conclusion

The present chapter outlined the methodology employed in the land suitability analysis. It further highlighted relevant assumptions about the project and limitations regarding the data used. A detailed inventory of the steps followed in the analysis is also provided. The following chapter presents and discusses the results obtained using the specified methodology.

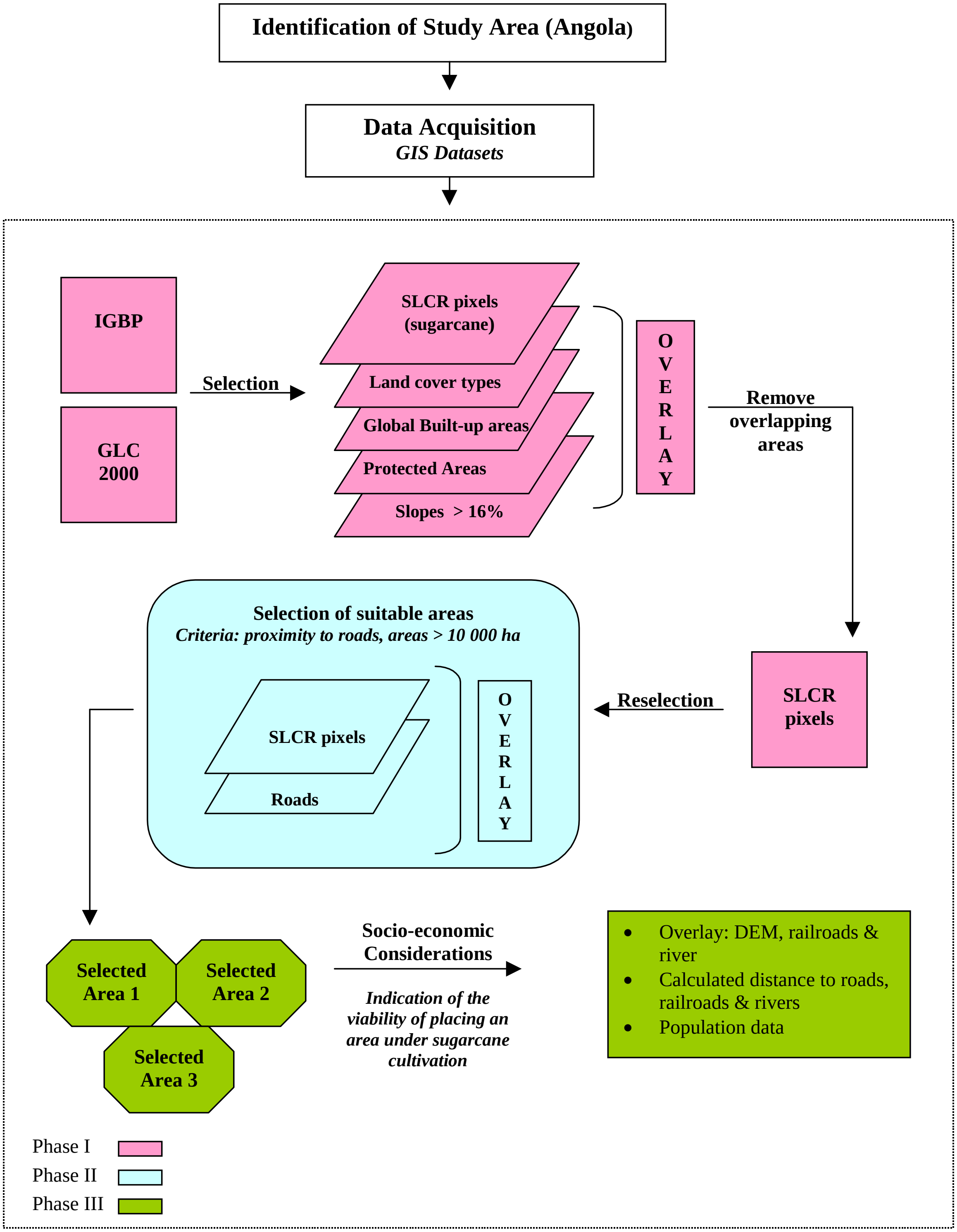

Figure 5.1. Flow diagram summarising Phases I, II, and III

Chapter 6
Results and Discussion

6.1. Introduction

The previous chapter outlined the methodological approach and methodology followed to yield results for the land suitability assessment for sugarcane. The following sections in this chapter present the results obtained and provides a discussion of these results. Specifically, the areas which are suitable for sugarcane cultivation without environmental constraints will be shown. This will be followed by the presentation of selected areas suitable for sugarcane cultivation based on non-biophysical considerations.

6.2. Seasonal Land Cover Regions

From the Miombo Network IGBP 1 km^2 Land Cover Product, areas that were identified as sugarcane were extracted. The resulting distribution of pixels are an indication of areas likely to be under sugarcane cultivation or under vegetation with similar phenology and production levels as sugarcane. As such these SLCR pixels are areas which are potentially suitably for sugarcane cultivation.

In Angola, 1.3% (16 262 km^2) of the total land area was identified as being potentially suitable for sugarcane cultivation (Figure 6.1.). It may appear that only a small area of Angola is suitable for sugarcane cultivation, however, considering that the amount of land required for cultivation on a commercial level is 100 km^2 (10 000 hectares), the identified suitable areas indicate a potential 162 commercial ventures. Thus, the areas identified as being suitable for sugarcane cultivation are indeed promising for commercial cultivation.

Distribution of pixels within the study area is not uniform, with an aggregation of suitable areas in the more westerly provinces of Bengo, Cuanza Norte, Cuanza Sul, Humbo, Bie, Huila and Cuando Cubango. (The reader is referred to Chapter 4, Figure 4.1. for a better understanding on the location of Angola's provinces). The reason for this is possibly due to the type of biomes that exist in those regions. Interestingly, SLCR pixels are mainly distributed in the *Tropical and Subtropical Grasslands, Shrubs and Savannas,* as well as *the Montane Grasslands and Shrublands* terrestrial biomes (Appendix A).

The *Tropical and Subtropical Grasslands, Shrubs and Savannas* biome occurs in the semi-arid to semi-humid climate of tropical and subtropical regions and is well known for its predominant grasslands. Furthermore, it is also well suited for perennial plants such as sugarcane. The *Montane Grasslands and Shrublands* biome is another grassland biome also containing shrublands found in the tropical, subtropical and temperate regions of the world (WWF, 2007). As sugarcane is most suited to tropical climates, the distribution of SLCR pixels in these regions is understandable (Sharpe, 1998). Based on this initial distribution of SLCR pixels, it can be seen that the Miombo Network IGBP 1 km^2 Land Cover Product has included vegetation of similar production levels and phenology to sugarcane in this classification. Therefore, the results are in agreement with the suggestions of Sys *et al.*, (1993), that it is possible that other C_4 plants which have growth production levels similar to sugarcane were also included among this initial distribution of SLCR pixels.

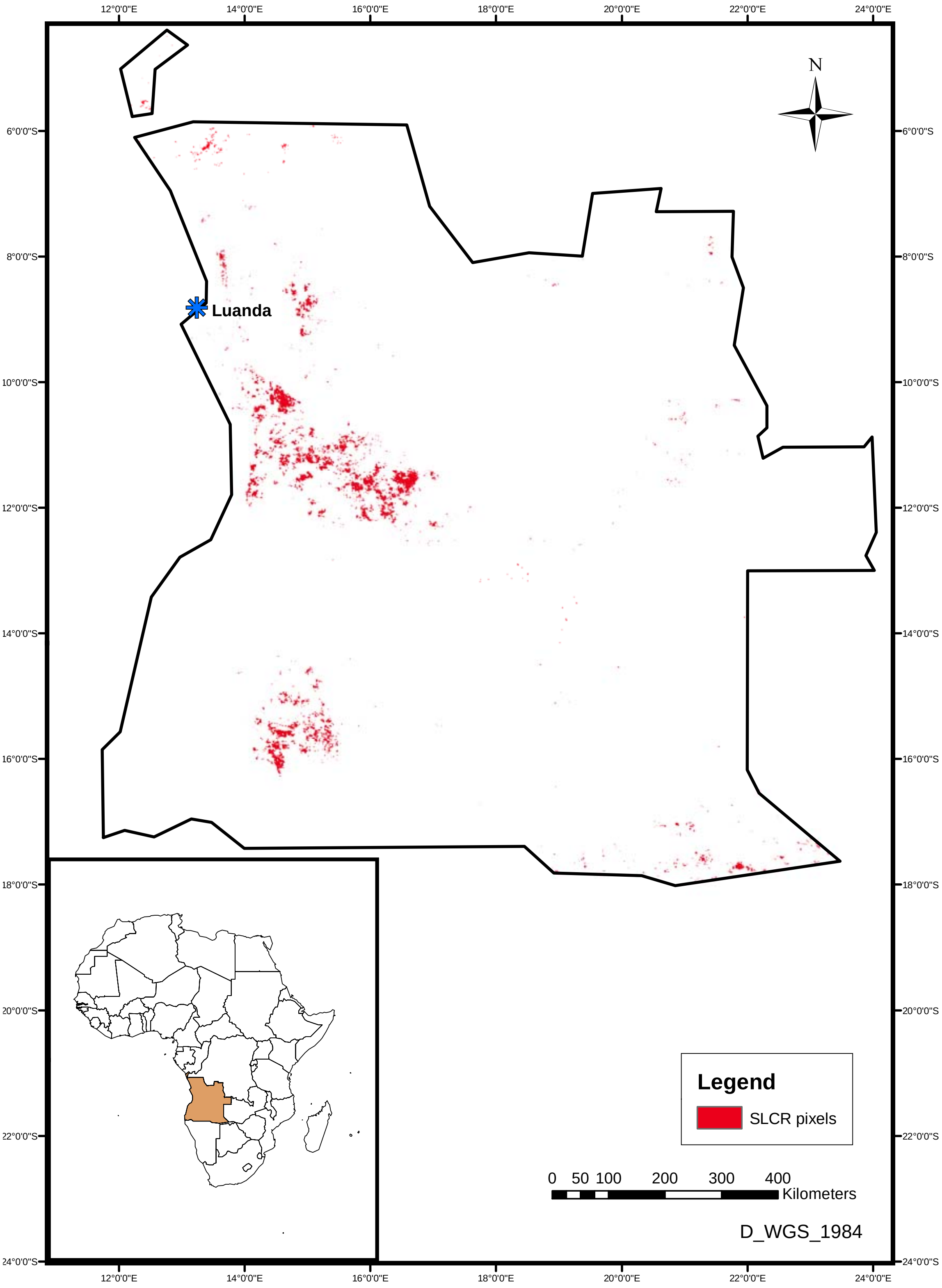

Figure 6.1. Distribution of SLCR pixels in Angola

6.3. Protected Areas

It is estimated that protected areas cover more than 12% of the world's land area. These include areas of "extraordinary species and ecosystems, irreplaceable examples of cultural and natural heritage, and refuges of peace and spirituality" (Wells and McShane, 2004). As such, protected areas become the foundation of managing and conserving the world's biodiversity as well as the numerous market and non-market benefits provided by these natural systems (Bruner *et al*., 2004). This imperative was echoed by the 1987 Brundtland report, "Our Common Future", in which the conservation of species and ecosystems featured highly amongst its list of priorities (Westley *et al*., 1998). This popular report therefore, became the start of a paradigm shift towards the concept of sustainability, and as such the designation of protected areas have no doubt played a critical role towards realising this shift.

In order to uphold and promote the concept of sustainability in this project, SLCR pixels which were located in protected areas were removed from the initial distribution and excluded from any further suitability analyses. Further reasons for removing overlapping SLCR pixels with protected areas are highlighted in Chapter 5, section 5.6.2. According to the 2006 WDPA database, 7.9% (98 510 km^2) of Angola's total land area is protected. Figure 6.2. shows that of this total area, national parks, partial/integral nature reserves and habitat/species management areas constitute 81 810 km^2, which constitutes categories II, VI and V respectively.

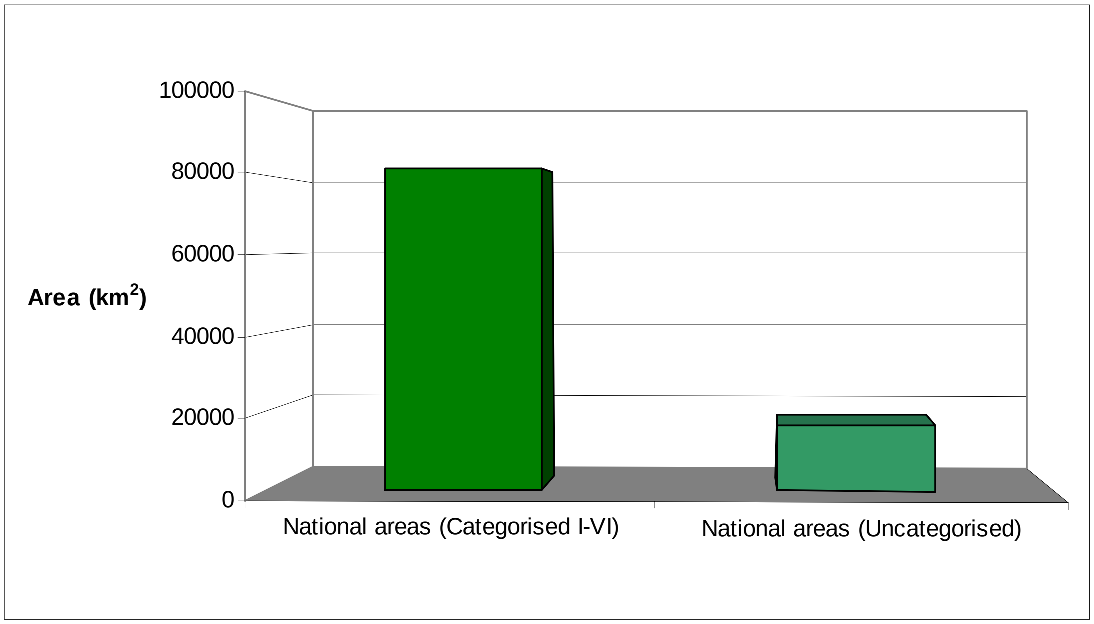

Figure 6.2. Area occupied by each protected area category in Angola

The remainder of the protected areas (16 700 km^2) is occupied by the Coutada da Pública da Luengue Hunting Reserve located in the south-eastern province of Cuando Cubango (Figure 6.3.) (http://sea.unep-wcmc.org/wdpa). Table 6.1. shows that 2310 km^2 SLCR pixels currently located in protected areas were filtered out. This reduced the total area potentially suitable for sugarcane cultivation by 14%. Figure 6.3. shows the spatial distribution of protected areas within Angola and the distribution of SLCR pixels after removing overlapping areas is presented in Figure 6.4.

Table 6.1. Area of overlapping SLCR pixels filtered out of protected areas

Protected Area	Area of filtered SLCR pixels (km^2)
National Areas (Categorised I-VI)	**1692**
National Areas (Uncategorised)	**618**
Total	**2310**

It is imperative to manage the use of protected areas especially in relation to population pressure and cultivation. Undoubtedly, expanding population places pressures upon protected areas and this is thought to be instigated to a large extent by the need for agricultural expansion (Madulu, 2001). It is suggested that this expansion of agriculture for commodity production is an integral cause of habitat conversion (Niesten *et al*., 2005). This trend is particularly noted in developing countries where areas dedicated to soybean, oil palm, cocoa and coffee have doubled over the past three decades (Verweij and de Man, 2005). Coupled with growing agricultural demand as a result of booming population growth, protection measures therefore become essential, especially in regions of high biodiversity. This is particularly relevant in Angola, as post-civil war the country is in a state of rebuilding its infrastructure of which agricultural expansion is an essential contribution. Furthermore, agriculture in the country is mainly rural, a family-labour activity for smallholder subsistence peasants with 85% of the population engaged in agriculture (FAO, 2006; CIA, 2007). Thus, population growth coupled with agricultural expansion makes it even more imperative to efficiently manage Angola’s protected areas. For these reasons, SLCR pixels which fell within protected areas were not considered, as cultivation within those areas would indeed refute sustainability.

Where such linkages between the environment and population occur, it becomes imperative in incorporating demographic considerations into the management and land use plans of protected areas (Madulu, 2001). Specifically, by using the example of the Swagaswaga Game Reserve (SGR) in Tanzania it can be seen how essential such considerations are.

With Tanzania’s population increasing at a rate of 3% annually, total population is expected to double from 30 million to 60 million by the year 2020 (PRB, 1997; cited in Mwamfupe, 1998, pg. 3). Population growth has increased the need for resources such as land for cultivation and grazing consequently leading to deforestation and encroachment of protected areas. Particularly, the reality of this pressure has become evident in SGR.

The SGR combines the former Songa Forest Reserve, Simbo, Swagaswaga and Handa forests as well as other adjacent forests (Madulu, 2001). The main objectives of protecting the reserve are avoiding soil erosion on hill slopes and protecting pasture and habitat of various wildlife species found in that area. The main economic activity conducted in villages adjacent to the SGR is subsistence crop cultivation with finger millet as the main crop. The local community surrounding SGR are aware of the restricted activities within the reserve such as tree felling, illegal hunting, illegal logging, however, even though cultivation is the most destructive human activity in the game reserve, it is not regarded as restricted by the local people. The main reason for this is that cultivation inside the game reserve is seen as a survival strategy during drought years and as such becomes an essential means of supporting rural livelihood (Madulu, 2001). According to Mwamfupe (1998), such encroachments into protected areas is seen as an act of desperation. However a means by which to promote sustainable use is the encouragement of collaborative participation between the political sector and local communities. As sustainable development has to be both people-centred and conservation based, for effective protected area management and expansion, a balance between the two has to be established.

According to the FAO-IIASA (2007) study, *'Mapping biophysical factors that influence agricultural production and rural vulnerability'* the Coutada da Pública da Luengue Hunting Reserve (Figure 6.3.) in the Angolan province Cuando Cubango is a protected area which has been mapped as being an area where agriculture is likely. Since 618 km^2 of SLCR pixels were filtered out from this area (Table 6.1.), the considerations mentioned in this section become of particular significance in the management and sustainable use of the nature reserve. Cuando Cubango is considered as one of Angola's least developed provinces as it still bears the scars of war (CAAEI, 2007). The population in this province is mainly engaged in agriculture and animal husbandry, and due to population growth and need for additional agricultural land, encroachment into the reserve is possible (FAO, 2006).

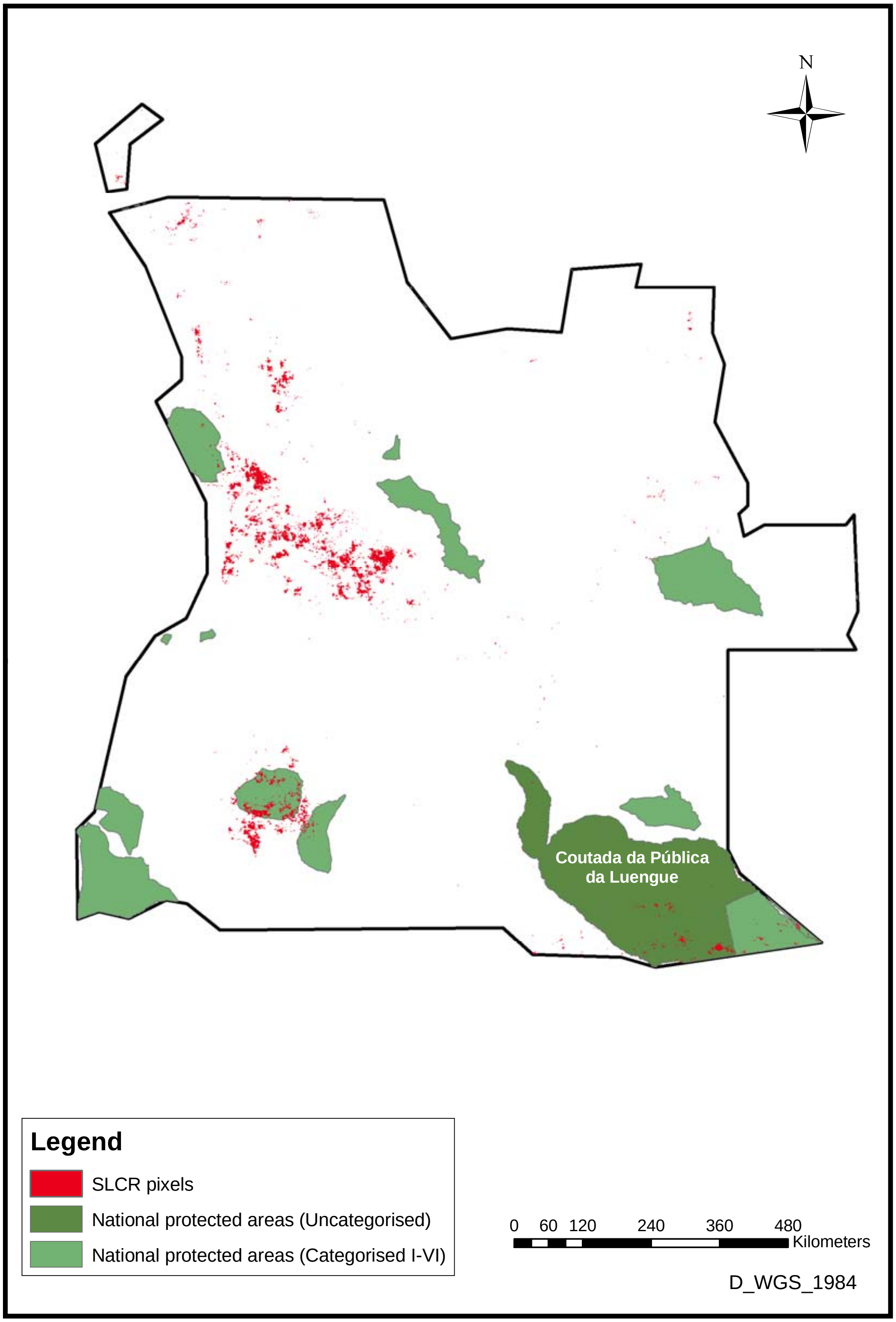

Figure 6.3. Distribution of SLCR pixels within IUCN protected areas

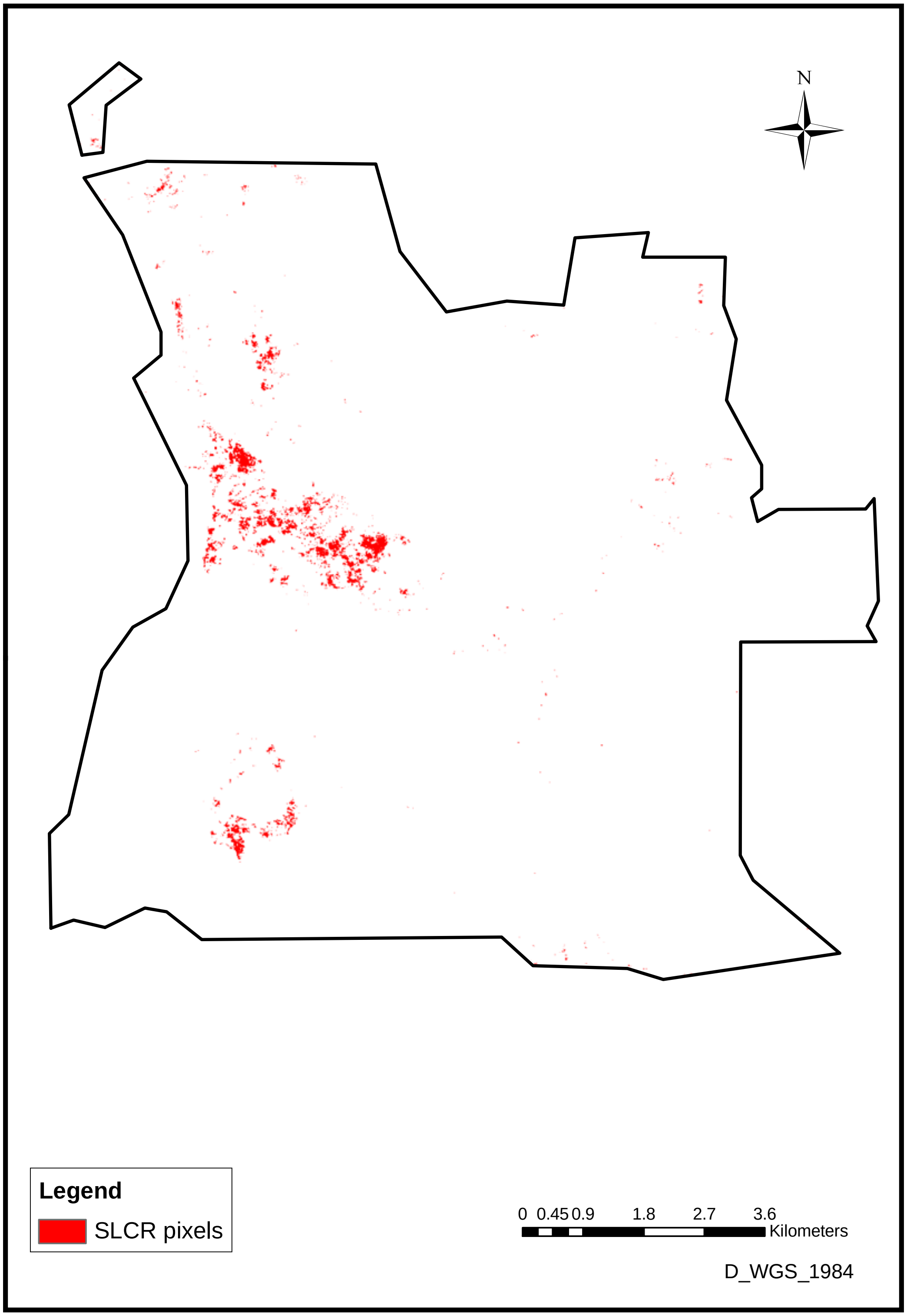

Figure 6.4. Distribution of SLCR pixels after filtering out protected areas

6.4. Global Land Cover

SLCR pixels which overlapped with land cover types that are considered unsuitable for sugarcane cultivation were removed. The basis of these land cover types being considered unsuitable is solely on ecological grounds, such that some land cover types such as swamps and salt hardpans are considered too moist and too saline for sugarcane cultivation, respectively. Land cover types such as croplands > 50%, closed deciduous forests, evergreen lowland forests, cities, built-up areas and waterbodies are areas which are considered unavailable for sugarcane cultivation. These areas are considered unavailable for cultivation from a sustainability viewpoint. Specifically, the ‘food versus fuel’ debate (discussed in Chapter 2) makes it essential to identify and highlight areas of current crop cultivation so as to not encroach upon already existing cropland for bioenergy purposes. Furthermore, the contentious issue of oil palm induced deforestation in SouthEast Asia (discussed in Chapter 2), makes it imperative to designate forests as unavailable for sugarcane cultivation for bioenergy purposes.

Land cover classes filtered out in this study are listed in Table 6.2. which also shows the area and percentage occupied by each class in the study area and the area of overlapping SLCR pixels in each land cover class. The distribution of SLCR pixels overlapping with the chosen land cover classes is shown in Figure 6.5. A total of 33.6% of Angola was filtered out as ecologically unsuitable and unavailable for sugarcane cultivation, corresponding to the land cover classes listed in Table 6.2. The land cover occupying the largest area in Angola (322 403 km^2) are the closed deciduous forests which are located in the central to eastern region. In conjunction with the evergreen lowland forest, sub-montane and montane forests the total filtered out forest cover is equivalent to 344 214 km^2, equating to 28% of the country’s total land area. However, perusal of the literature reveals several sources that indicate that forests cover a much larger area of Angola. Examples of these sources are FAO (2002b), Global Forest Watch (2007) and Johnson and Rosillo-Calle (2007), which indicate that 697 560 km^2, approximately 56% of the country’s total land area is covered by forests. The difference between the forest area identified in this study and those identified by those authors is likely to be due to how forests are defined. Specifically, the FAO define forests as “Land spanning more than 0.5

hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ" (FAO, 2004b). On the other hand, the GLC 2000 defines forests (including closed deciduous and evergreen lowland forests) with a tree canopy cover greater than 70% and a height greater than 5m (European Commission Joint Research Centre, 2003). By comparing the two definitions it can be understood why there is such a difference in the reported forest areas in Angola. Furthermore, the GLC uses a higher resolution data of 1 km^2 whereas for example, the FAO (2002b) uses a much lower resolution data. Owing to the higher resolution of the GLC 2000 land cover database, it is likely that all SLCR pixels which were located in forest areas have been removed. However, it is acknowledged that with higher resolution data (for example 1m, 2.5m, 5m, or 10m), accuracy of filtering out overlapping areas would be greatly increased.

The Angolans consider their forests as a treasured natural resource providing both wood and non-wood products. It has socio-economic value and underlying significance for the welfare of the people and to the national economy (EC-FAO, 1999). In addition to production of timber, forests have provided other products which are used daily for food, medicinal and other purposes (EC-FAO, 1999). These include honey, wax, medicinal plants and bushmeat. Thus, ensuring that cultivation for bioenergy purposes does not instigate deforestation is a critical sustainability concern, especially since one of the main environmental concerns in Angola is deforestation which is occurring at an annual rate of 0.2% (FAO, 2002b). Forests, in general provide other essential functions which included mitigating climate change (by reflecting less heat back into the atmosphere), coastal protection and acting as air-pollution filters (FAO, 2005a).

Table 6.2. Area occupied by each land cover class in Angola and number of overlapping SLCR pixels filtered from each class

Land cover type	Area occupied in Angola (km^2)	Percentage occupied of total land area (%)	SLCR pixels filtered in each class (km^2)
Bare rock	5 716	0.42	0
Built-up areas	160 (*28)	0.01	7
Closed deciduous forest	322 403	25.8	1610
Cropland > 50%	52 429	4.2	766
Cities	194	0.02	0
Evergreen lowland forest	21 671	1.7	216
Montane forest	115	0.01	0
Salt hardpans	159	0.01	0
Sandy desert and dunes	23 499	1.9	0
Stoney desert	4 393	0.4	0
Submontane forest	25	0.002	0
Swamp bushland and grassland	6 831	0.55	16
Water bodies	365	0.03	0
Total	**418 960**	**33.6**	**2 615**

***** number of built-up areas

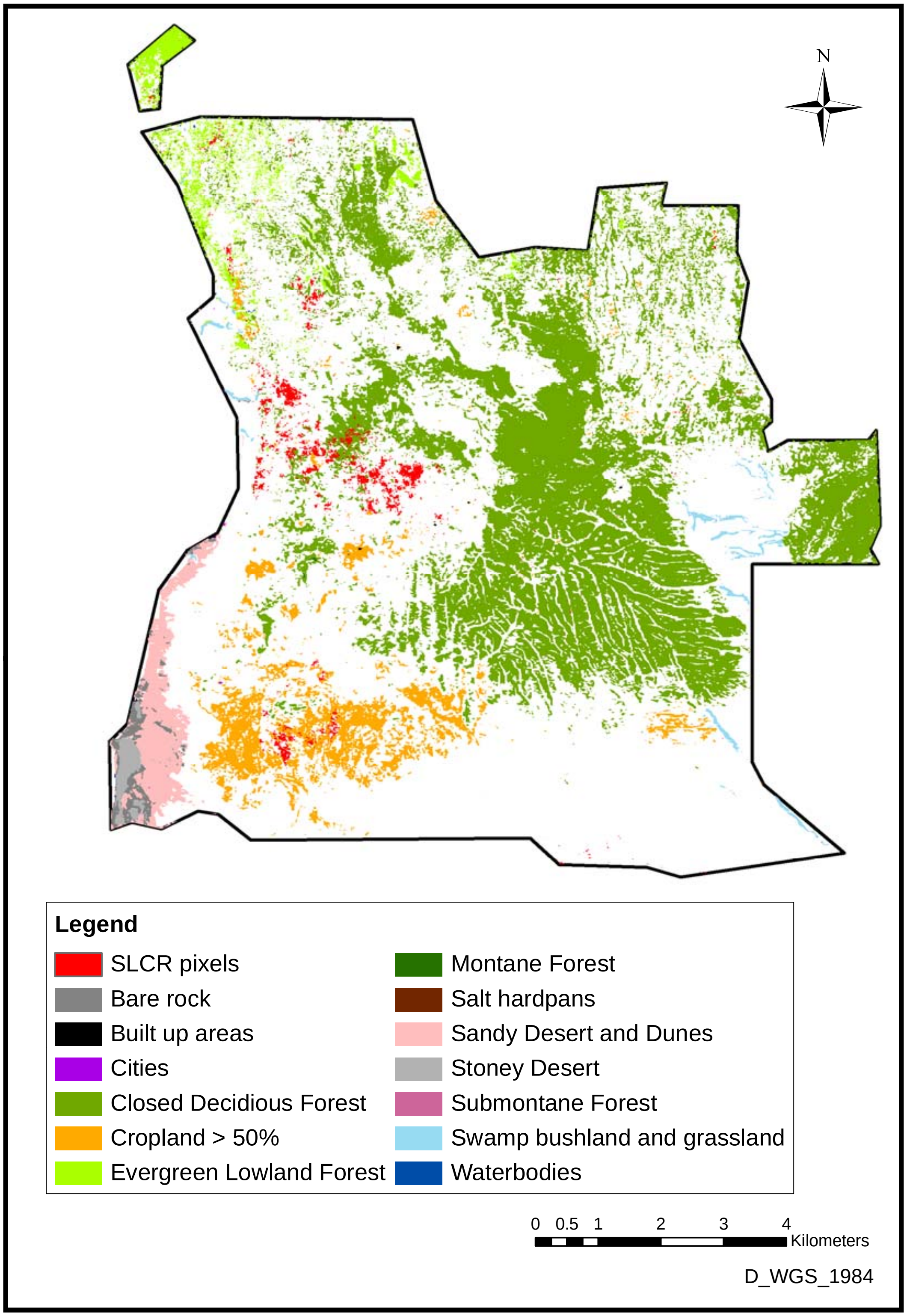

Figure 6.5. Distribution of SLCR pixels within Global Land Cover classes

In addition, several ecological reasons supported the removal of overlapping SLCR pixels with the chosen forest land cover classes. For example, the GLC 2000 defines montane and sub-montane forests as “forests occurring at greater than 1000m above mean sea level”. Considering the environmental factors influencing successful sugarcane cultivation, reasons for excluding pixels which overlapped with montane and sub-montane forests becomes clear. Altitude is one such factor which influences the growth cycle of sugarcane, and therefore sugarcane is typically cultivated up to 1600m above sea level. Even though there is a common range of 600m between the two definitions, altitudes in excess of 1600m would prove not suitable for sugarcane cultivation. However, it is not clear why forest areas would have areas with a spectral signature equivalent to sugarcane, unless there are open patches in these areas supporting tall grasses or reeds, or vegetation with similar phenology to that of sugarcane. It is recommended that Google Earth® be used to investigate this phenomenon further.

Out of the several forest land cover classes, SLCR pixels (1610 km^2) only overlapped with closed deciduous forests and evergreen lowland forests (216 km^2).

The second largest land cover class occupying Angola is that of croplands > 50%. Currently, not more than 40 000 km^2 (4 million hectares) of land are under crop cultivation in Angola (Johnson and Rosillo-Calle, 2007; Makenete, 2007; Van Den Berg and Rademakers, 2007); however the GLC 2000 land cover database has identified 52 429 km^2 of cropland in Angola. This area exceeds the current area under cultivation by a minimum of 10 000 km^2. The European Commission Joint Research Centre (2003), producers of the GLC 2000 land cover database, has acknowledged the difficulties associated with the detection and mapping of agricultural systems in Africa using remotely sensed data. Specifically, fields are small, and mixed savanna and fallows “preclude a reliable mapping at a spatial resolution of 1 km^2” (European Commission Joint Research Centre, 2003). On the other hand, it is further suggested that, “the low intensification level of agricultural techniques induces spectral or temporal properties of agriculture close to the surrounding vegetation” (European Commission Joint Research Centre, 2003). Thus, it is possible that the croplands identified by the GLC 2000, may include areas which are not in reality under crop cultivation and may account for the 10 000 km^2 cropland excess.

Another possible reason for this excess is that the cropland land cover class may have included agricultural areas which constitutes 576 000 km^2 (57.6 million hectares) in Angola (Johnson and Rosillo-Calle, 2007). It is important to note that there exists a difference between cultivated and agricultural areas; agricultural areas includes temporary and permanent pastures and temporary and permanent crops whereas cultivated areas exclude temporary and permanent pastures (Johnson and Rosillo-Calle, 2007). Since the European Commission Joint Research Centre (2003) defines croplands > 50% as areas of intensive cultivation with over 50% cultures or pastures, it is more than likely that this land cover class includes a small portion of agricultural areas, thereby accounting for the 10 000 km^2 excess.

Out of the four agricultural land cover classes identified by the GLC 2000 (croplands > 50%, tree crops, irrigated crops and croplands mixed with open vegetation), only croplands > 50% were identified in the study area, occupying 4.2% of the total land area. A total of 766 km^2 of SLCR pixels were found overlapping with croplands and were subsequently removed. As previously mentioned, SLCR pixels are likely to include areas under sugarcane cultivation, however, by filtering out overlapping SLCR pixels with the cropland land cover class, most of the pixels corresponding to areas under sugarcane cultivation would have been removed.

In addition, 16 km^2 SLCR pixels were also found overlapping with swamp bushland and grassland. This land cover class was considered not suitable for sugarcane growth as it often has standing water in depressions due to the nature of its topography. Furthermore, due to excessive water, swamp bushlands and grassland may prove harmful to sugarcane yield production (Griffee, 2000).

Built-up areas made up the remaining overlapping pixels with 7 km^2 overlapping SLCR pixels. It is interesting to note that no pixels overlapped with the cities land cover class identified by the GLC 2000. For this reason, the global built-up areas database had to be used as supplementary information on cities and built-up areas in the study area. The underlying reason for removing overlapping SLCR pixels with cities and built-up areas was to ensure that areas identified as suitable for sugarcane cultivation did not include areas of human settlements. However, the inclusion of rural settlements would have proven to be a more accurate representation of human settlements. Due to the lack of such data at the level of the study area, this was excluded from the analysis. Therefore it is possible that a percentage of SLCR pixels may actually fall within areas of human settlements, which would require verification by higher resolution, higher precision and up-to-date data.

In general, it has been acknowledged that there exists inherent challenges to the mapping of urban and rural populations (FAO, 2005b). Some of the major challenges include a lack of standard definitions of what constitutes an urban or rural area and the criteria used to distinguish between the two. Imprecision of datasets currently available for determining the location of human settlements (e.g. GLC 2000) is another challenge. In addition, statistical information on population distributions varies on a country basis and therefore lacks comparability (FAO, 2005b).

Other land cover classes included in the filtering process using the GLC 2000 included bare rock, stoney desert, salt hardpans and water bodies. None of the SLCR pixels overlapped in these land cover classes. However, the reason for excluding overlapping pixels in these classes are related to ecological considerations, such that bare rock and stoney desert are areas of erratic or inexistant rainfall (European Commission Joint Research Centre, 2003). As such, conditions in these areas would prove too harsh for sugarcane growth which is a highly water demanding crop (Hunsigi, 1993; cited in Cornland *et al.*, 2001, pp 34). Since sugarcane can tolerate only moderately saline conditions, salt hardpans may prove too dry and saline for sugarcane. It has been noted that as salinity increases, crop yields tend to decrease (Griffee, 2000).

The distribution of SLCR pixels after removing overlapping areas with the chosen land cover classes is shown in Figure 6.6. A total of 2615 km^2 of SLCR pixels were filtered out due to overlap with the chosen land cover types. This further reduced the distribution of areas potentially suitable to sugarcane cultivation by 30% (11 337 km^2).

Since SLCR pixels were not located in most of the land cover classes, it further verifies that both the GLC 2000 and MIOMBO datasets are indeed reliable. Specifically, as the MIOMBO SLCR pixels are equivalent to the spectral signature of sugarcane, it has been verified by these results that one would not expect to find a spectral signature of a surface equivalent to sugarcane or similar grasses in bare rock, salt hardpans, sandy desert and dunes, stoney desert, submontane forests, etc. The fact that SLCR pixels were filtered out from built-up areas may reflect age differences of datasets such that it is likely that those built-up areas were constructed after the MIOMBO dataset was used to identify seasonal land cover regions (SLCR).

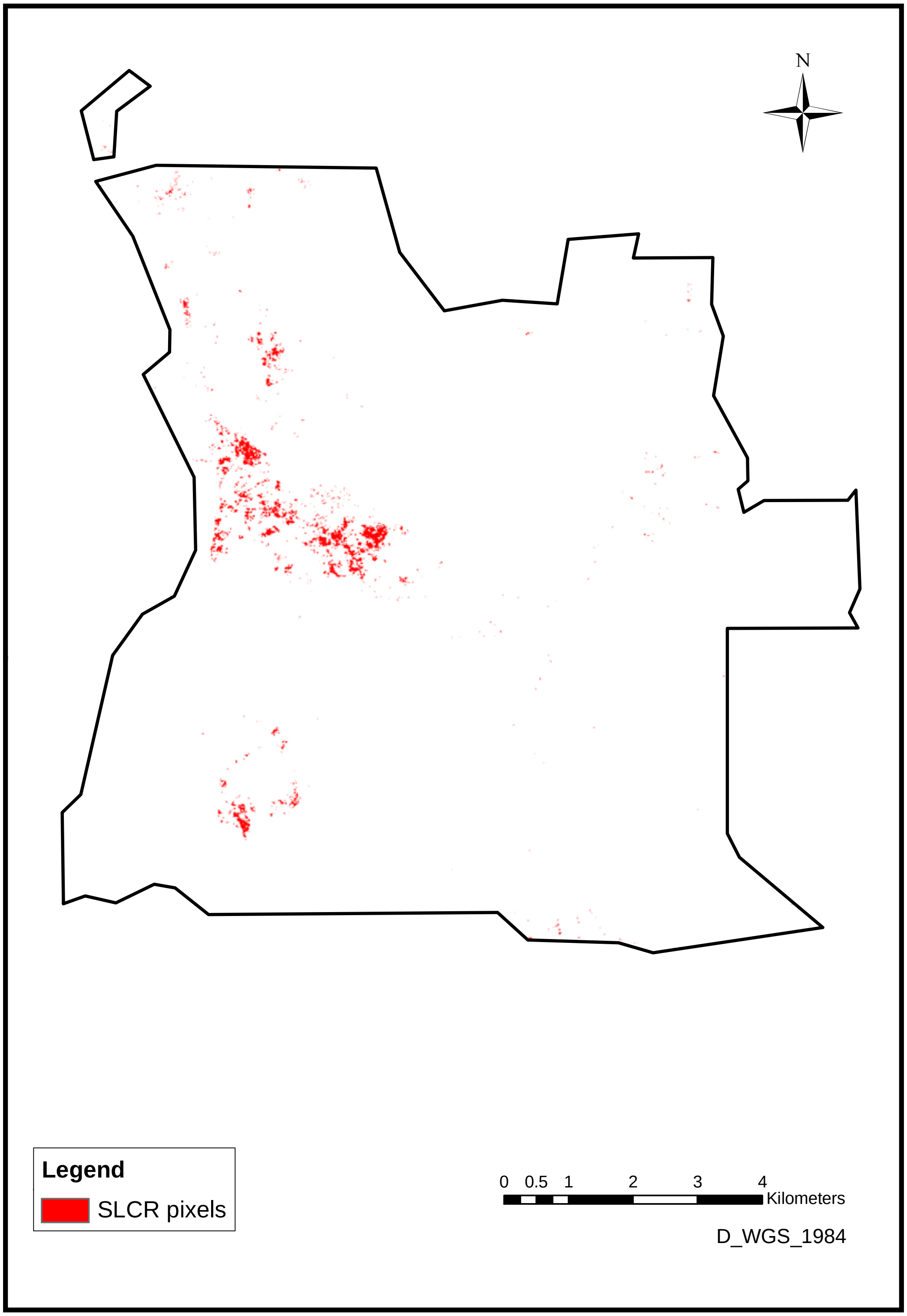

Figure 6.6. Distribution of SLCR pixels after removing areas overlapping with Global Land Cover classes

6.5. Terrain constraints

It is well established that sloping terrain poses more difficulties to cultivation than flat land (Sys *et al*., 1991; Eldridge, 2004; FAO-IIASA, 2007). In addition, sloping terrain is subject to higher rates of water run-off and soil erosion, and in general it is understood that steeper the slope, the greater is the constraint to productivity potential (FAO-IIASA, 2007). According to Sys *et al*., (1991), this element of landform plays an essential role especially when considering mechanised cultivation. Those authors suggest that for slopes steeper than 20%, mechanisation becomes impossible and for slopes less than 20% there still exists variations in productivity according to variations in slope. It is further suggested by Navas and Machin (1997, cited in Ghaffari *et al*., 2000, pg. 7) that in order to avoid machinery induced soil erosion and other problems derived from the use of machinery, only land with slopes below 8º (equivalent to 17,8%) should be used. However, these constraints can be relieved by some extent by the use of terraces, but an associated increase in the likelihood of soil erosion should be expected (Sys *et al*., 1993; FAO-IIASA, 2007).

For the reasons outlined a threshold slope value of areas 16% and greater was considered as unsuitable for sugarcane cultivation. Slope in percent in the context of land suitability studies is the “rise in elevation in meters over a range of 100m” (FAO-IIASA, 2007).

SLCR pixels distributed in land with slopes greater than 16% were filtered out. Only 58 km^2 of SLCR pixels occurred in slopes greater than 16% and these were mainly located in the northern region of the country. As this is a relatively small number of overlapping pixels, it is difficult to compare the distribution of SLCR pixels after removing overlapping areas with Figure 6.6. Figure 6.7. shows the distribution of SLCR pixels after filtering out protected areas, global land cover classes and slopes greater than 16%. As a result of the several filtering steps in the analysis, the initial distribution of SLCR pixels (Figure 6.1.) has been reduced by 30% with the final distribution of areas potentially suitable for sugarcane cultivation being 11 279 km^2.

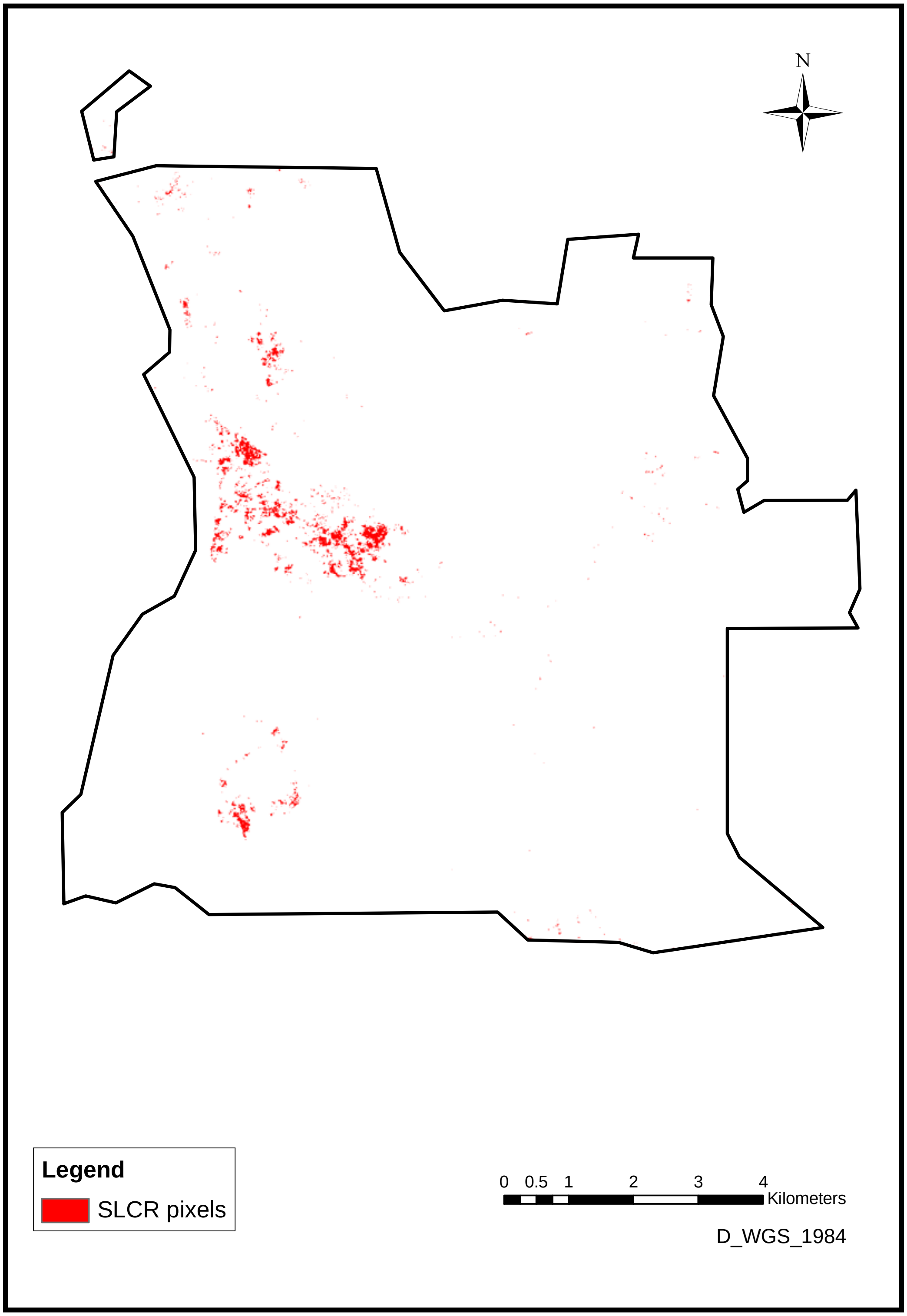

Figure 6.7. Distribution of SLCR pixels after filtering out slopes greater than 16%

However, despite the disadvantages associated with cultivation on steep slopes, there may be cases in which such cultivation becomes necessary. Often as a result of population pressures especially in rural areas which practice small scale farming, cultivation on steep slopes is one means by which to increase the amount of land available for farming. The most important factor to be controlled in such conditions is soil erosion (Eldridge, 2004). In the case of sugarcane farming this can be achieved by adopting reduced tillage and zero tillage farming systems, and by retaining a burnt cane trash blanket on the soil surface (Eldridge, 2004). Intercropping may also prove to be a useful measure in controlling soil erosion as it assists in binding the soil thereby reducing soil erosion (Alexander, 1985; Blume, 1985).

6.6. Selected Areas

The areas identified in Figure 6.7. are suitable for sugarcane cultivation based only on biophysical considerations, i.e. they are an indication of potentially suitable areas for sugarcane cultivation only in terms of where it is best to grow sugarcane without environmental constraints. However, in order to determine the viability of establishing sugarcane farms at the areas identified, a further selection process was needed, taking into account non-biophysical considerations involved in sugarcane production, as outlined in Chapter 3. Proximity to roads was an obvious criterion, due to the transport requirements of sugarcane farms. Specifically, areas which were in close proximity to primary roads were selected as being most viable for establishing a sugarcane farm. Reasons substantiating the choice of criteria have been outlined in Chapter 5. In conjunction with proximity to roads, a criterion of areas greater than 10 000 hectares resulted in the exclusion of 665 km^2 of SLCR pixels.

As the aim of this project was to identify areas suitable for sugarcane cultivation (and not specific sites), following this final filtering of SLCR pixels, three areas with a combined area of 10 614 km^2, were identified as being suitable for sugarcane cultivation. The selected areas are shown in Figure 6.8. and the area occupied by each selected area and the provinces in which it is located is listed in Table 6.3.

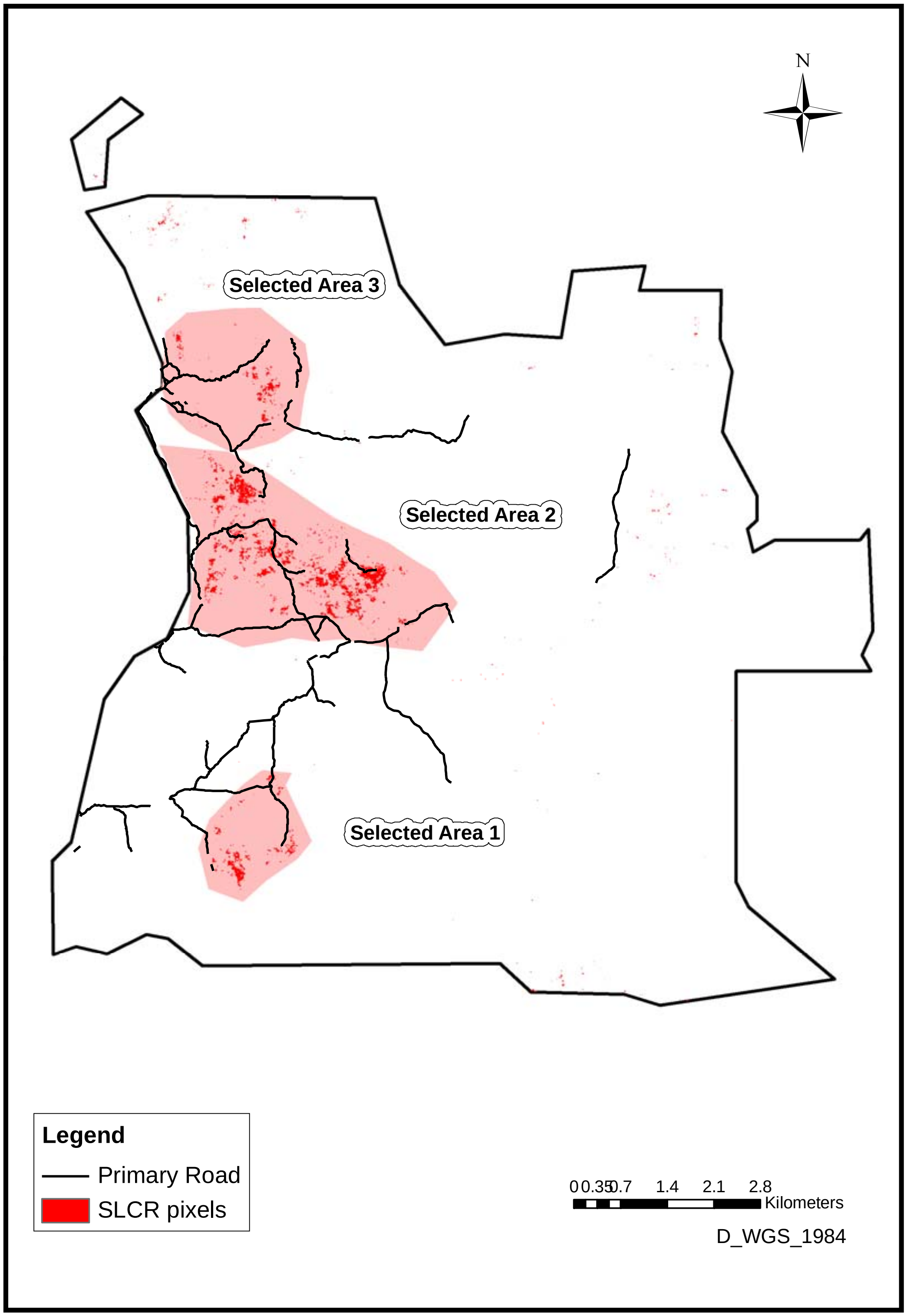

Figure 6.8. Three selected areas suitable for sugarcane cultivation

Table 6.3. Area of each of the selected suitable areas and provinces in which they are located

Selected area	SLCR pixels (km^2)	Region	Province
1	1 258	South	Huila, Cunene
2	8 397	Central	Cuanza Sul, Bie, Huambo
3	959	North	Luanda, Bengo, Cuanza Norte
Total	**10 614**		

The areas selected cover a large expanse, spreading over two provinces at minimum in all three selected areas. It is likely that these areas will be reduced to individual provinces following a complete land evaluation of the selected areas. This would include assessing the areas in terms of the surrounding social, economic and physical context as well as the availability of local and export markets, costs and benefits of input as well assessments of land tenure (FAO, 1976). Specifically, surveys at the semi-detailed or intermediate level would prove more meaningful by incorporating more specific aims and a feasibility study of the development project (FAO, 1976).

Proximity to transport infrastructure was further analysed at the level of each of the selected areas to establish distance from the agricultural area to both roads and railroads. Even though, not considered explicitly in this study, distances to transport infrastructure can be used in determining best possible locations of the manufacturing phase (i.e. mill) of a sugarcane farm or most cost-effective and practical means of reaching existing mills. Figures 6.9 through 6.14. gives a description of each of the selected areas with respect to distance to roads and railroads. Pixels in white indicate the closest proximity to the relevant transport infrastructure (road or rail).

The reader is urged to refer to the detailed maps provided in the Appendix for a better understanding of the locations of roads, railroads and cities in Angola.

6.6.1. Selected Area 1

The selected area is located in the southern region of the country and has 1 258 km^2 of land potentially suitable for sugarcane cultivation. Passing through the area is the Mocamedes railway (Figure 6.9.) which travels from Namibe to Cuanda Cubango. The Mocamedes would serve as a means of transporting high bulk produce and goods into and out of the agricultural area to major cities. In the agricultural area, the closest proximity to the railroad is in the northern region located in the Huila province. Based on this, it can be suggested that tractor-trailer rigs should bring the cultivated material and goods to this region for loading. Selected area 1 also has a good distribution of primary roads surrounding it (Figure 6.10.). Specifically, located on the western, nothern and eastern periphery are two major roads which lead to Lubango, which is the nearest major city.

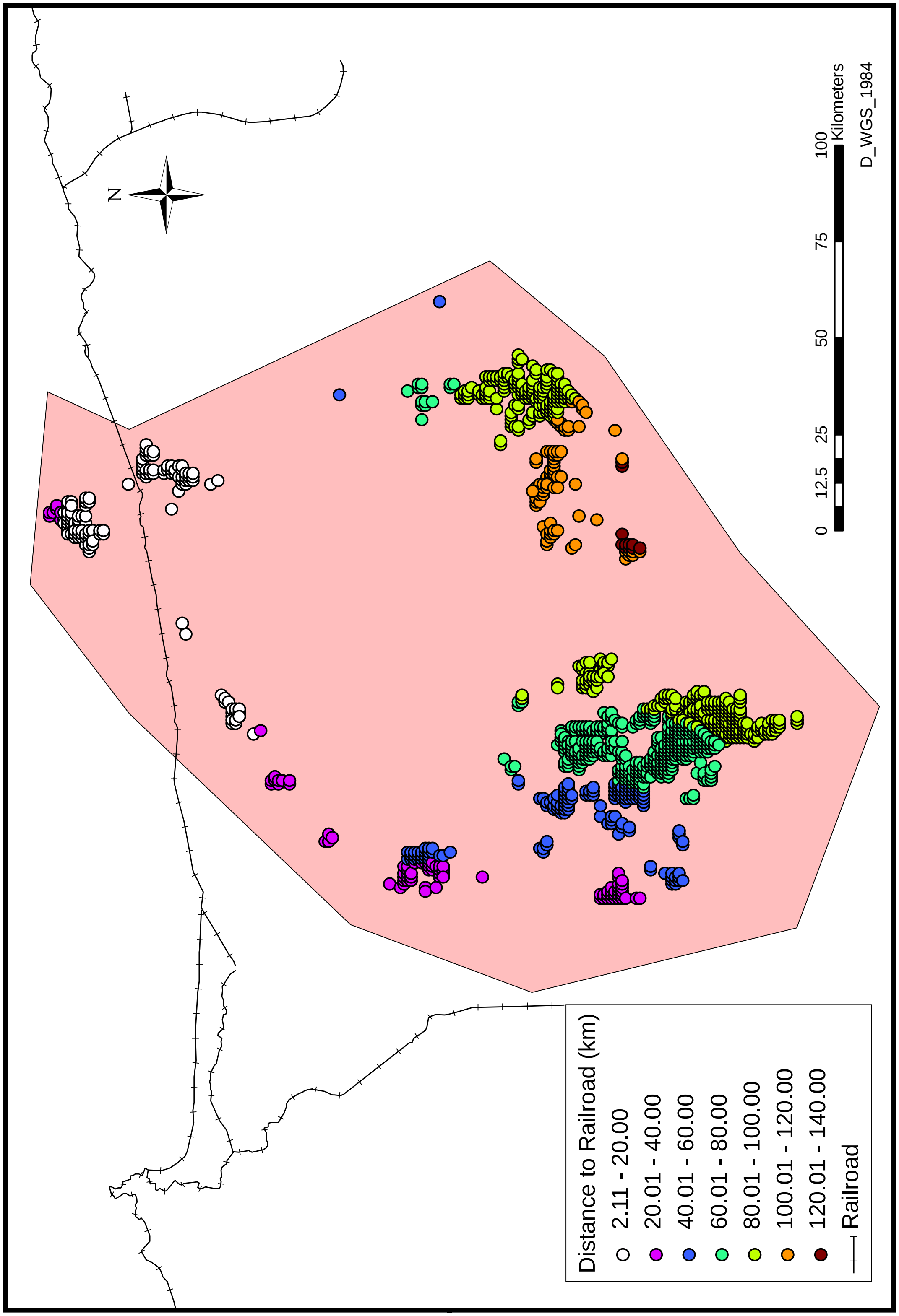

Figure 6.9. Proximity to railroads in Selected Area 1

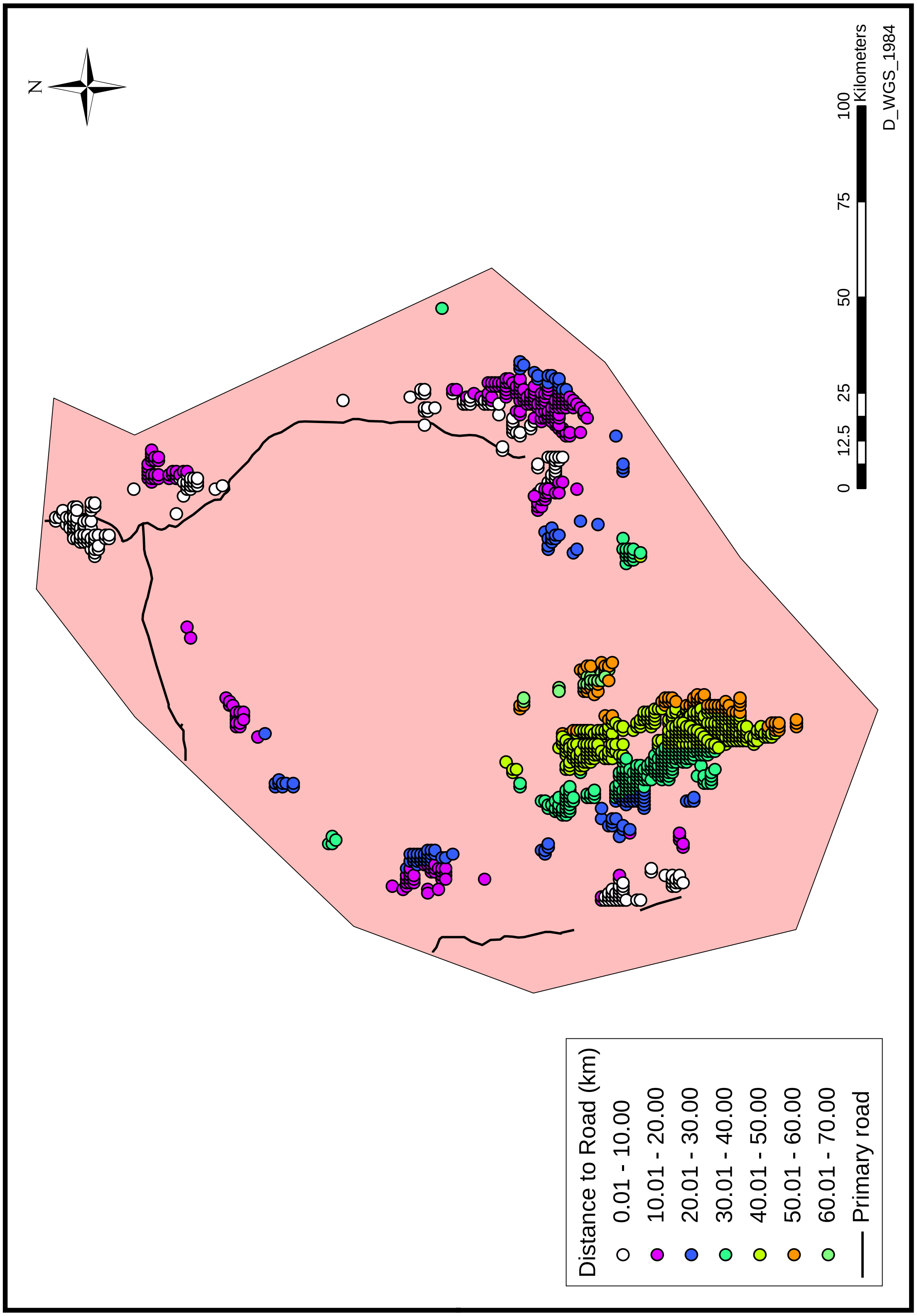

Figure 6.10. Proximity to roads in Selected Area 1

6.6.2. Selected Area 2

The selected area is located in the central region of the country and has 8 397 km^2 of land which is potentially suitable for sugarcane cultivation. It is the largest of the three selected areas, spanning three provinces. Passing through the area is the Benguela railway (Figure 6.11.) in the southern region of the selected area and the Luanda railway in the north. The area is situated in proximity to several major roads (Figure 6.12.) leading to cities Kunto, Ngunza, Huambo and Benguela. However, despite the generous distribution of road and rail transport infrastructure in this area, it is not certain as to the operational functionality of these systems because the central region of Angola is noted for its poor transport conditions (FAO, 2006).

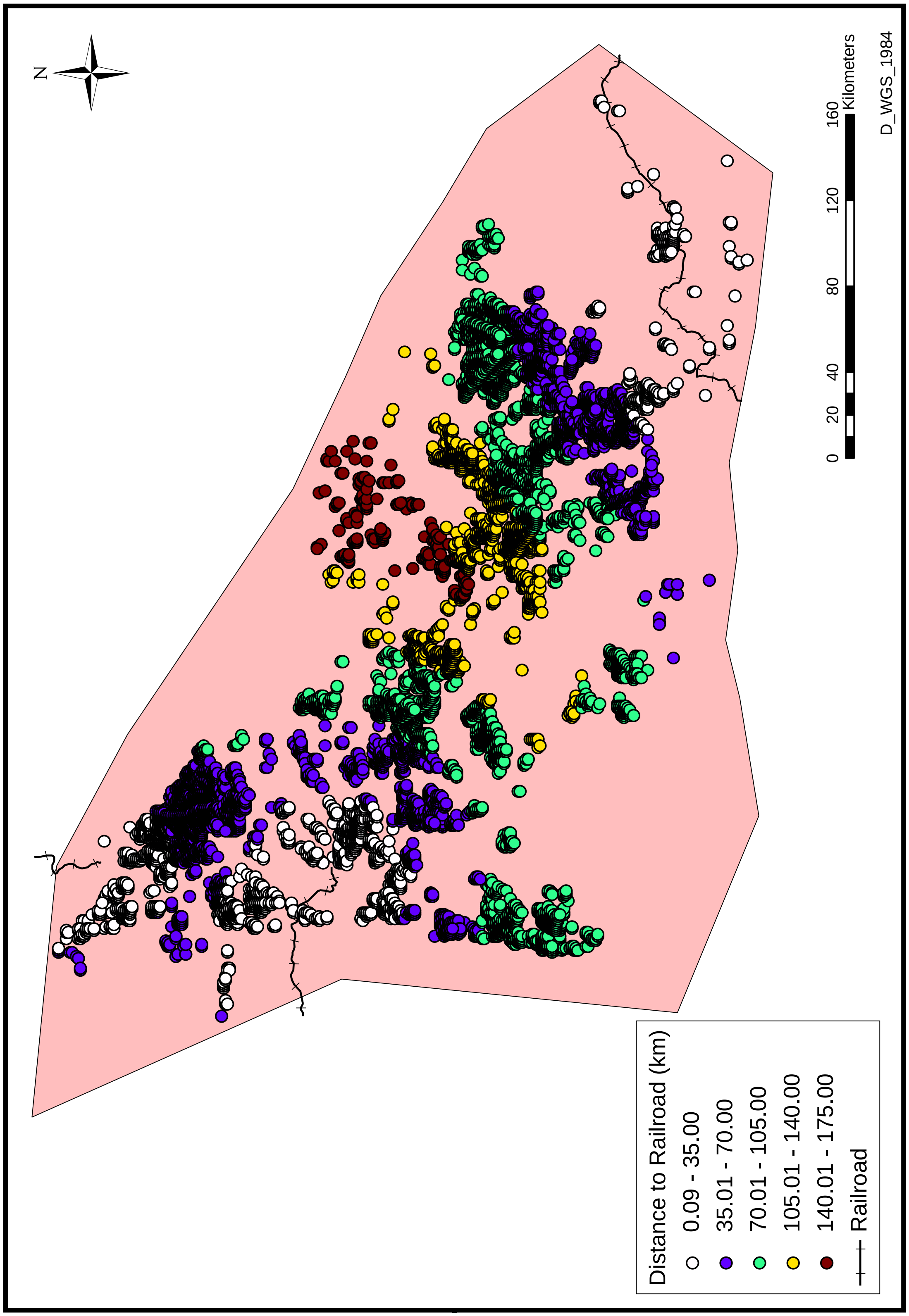

Figure 6.11. Proximity to railroads in Selected Area 2

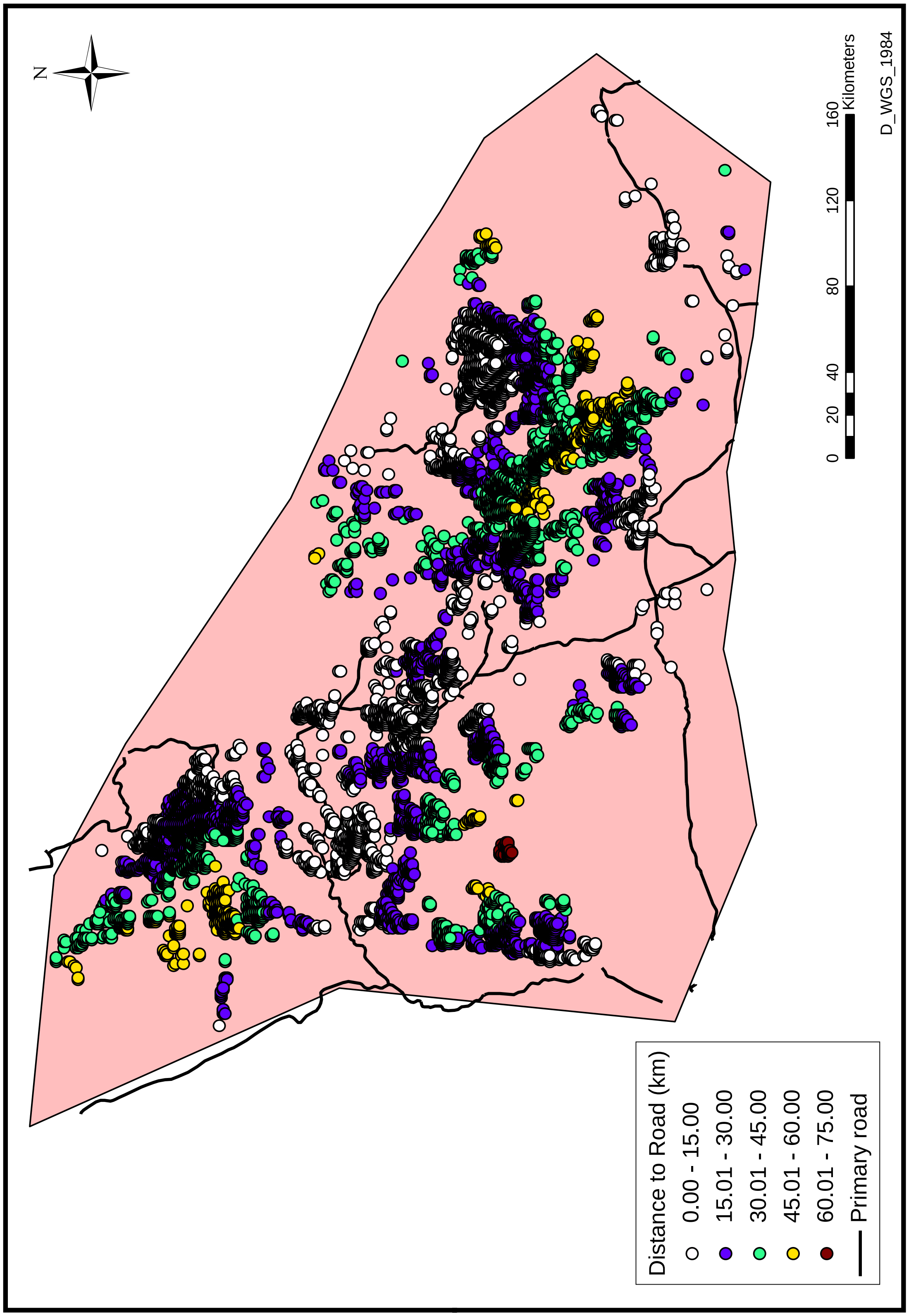

Figure 6.12. Proximity to roads in Selected Area 2

6.6.3 Selected Area 3

The selected area is located in the northern region of the country and is characterised by 959 km^2 of land potentially suitable for sugarcane cultivation. Passing through the central and southern parts of area is the Luanda railway (Figure 6.13.). There are several major roads passing through the area (Figure 6.14.) which facilitates access to the cities Ndalatando, Caxito, Luanda and Malanje. However, similar to selected area 2, the poor condition of the roads in this region poses a major constraint to the movement of commodities from production areas to markets (FAO, 2006).

The emphasis on using road and rail infrastructure in assessing the viability of establishing sugarcane farms at the selected areas is motivated by the link between food security and transport infrastructure. The FAO (2006) considers the improvement of road networks in Angola as a crucial factor in achieving full agricultural potential as roads provide a means of marketing agricultural produce without transport losses and prohibitive transport costs. The condition of Angola’s transport infrastructure has been discussed in Chapter 4 and the reader is referred to this chapter for a better understanding. It is possible that the condition of Angola’s transport infrastructure would be a limiting factor in establishing a sugarcane farm at the selected areas. However, regeneration of the country’s current infrastructure network is a top priority for the Government of Angola, and as such the limitation caused by poor transport infrastructural conditions may in the future be greatly reduced. The Ministry of Transportation has emphasised that the main objective of infrastructure refurbishment is to “guarantee the integrated functioning of all modes of transportation” and to guarantee a suitable system of urban transportation in the principle cities (Kuvingua, 2004). As this was a statement made in the year 2004, it is likely that road and rail upgrades have already been made. In 2006, large loans by the Chinese government has sped up the process of building roads and railways.

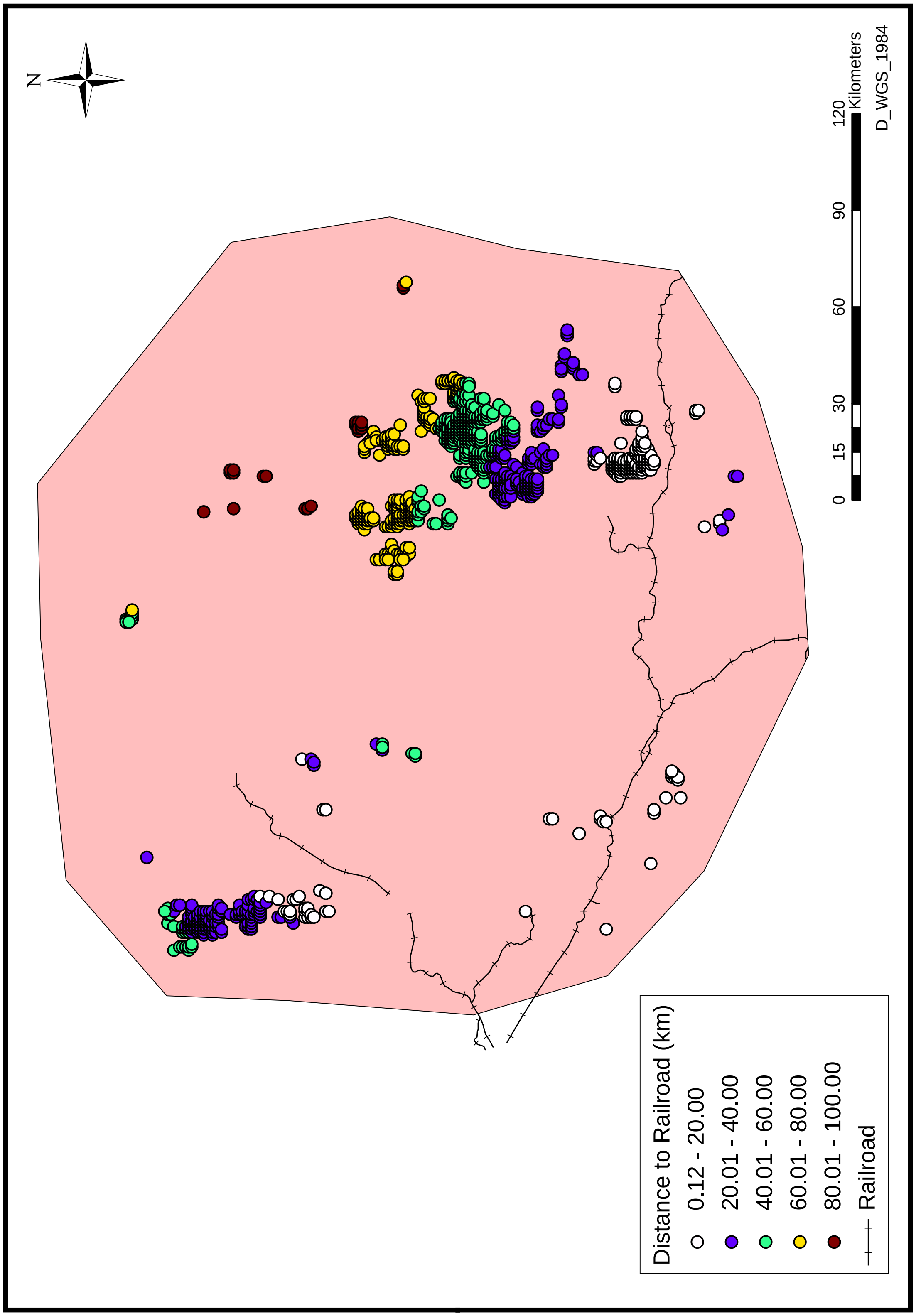

Figure 6.13. Proximity to railroads in Selected Area 3

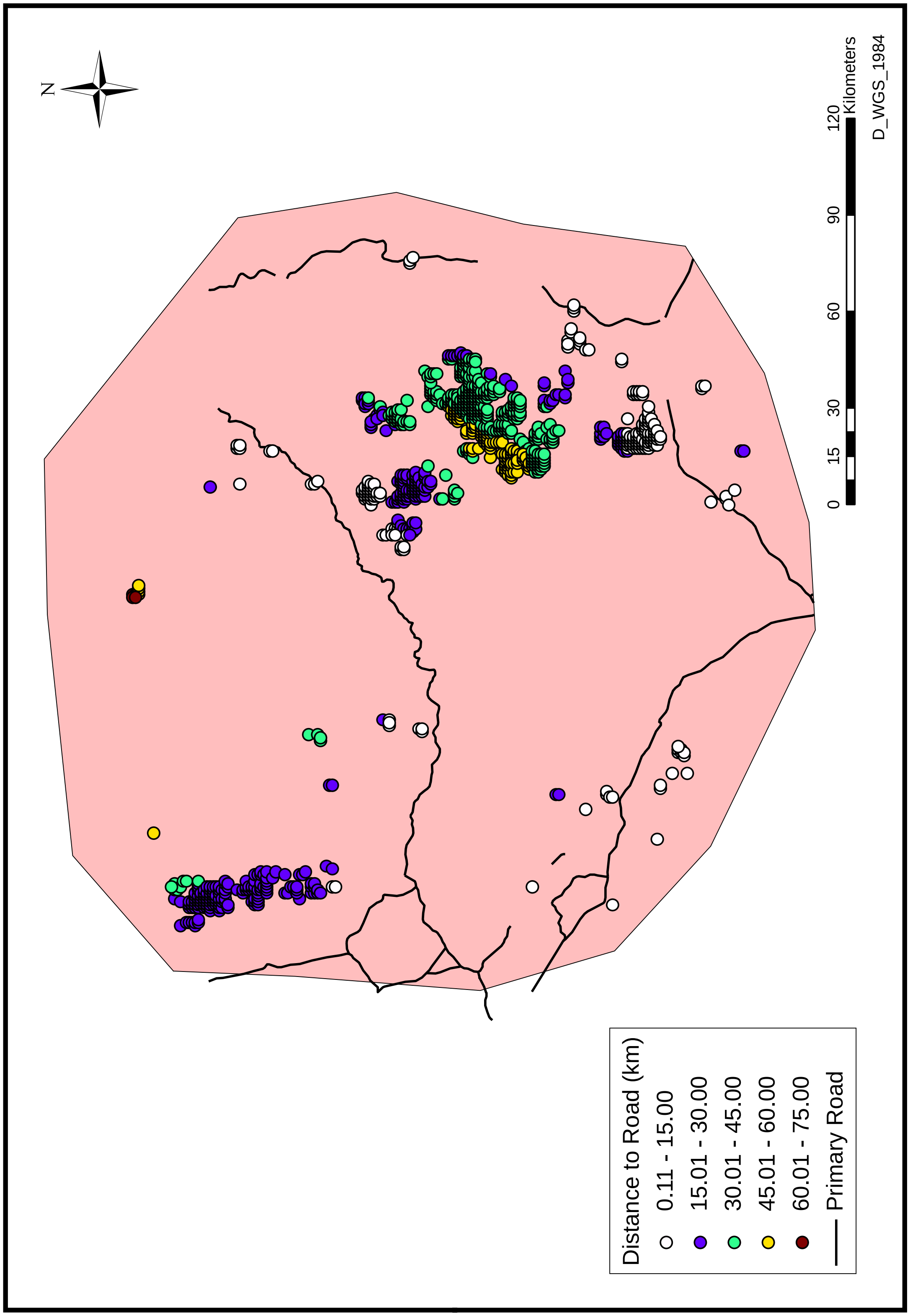

Figure 6.14. Proximity to roads in Selected Area 3

6.7. Population

With a total population of 15.94 million, Angola's population density sits at just under 13 people per square kilometer. Population and population density of each of the provinces located in the selected areas are listed in Table 6.4. The distribution of population in each province is shown in Figure 6.15.

Table 6.4. Population of each province within the selected area

Selected Area	Province	Population	Population density (persons/km^2)*	Total population
1	Huila	971 599	12.3	123 099 0
	Cunene	259 391	3	
2	Cuanza Sul	727 861	13	368 961 7
	Bie	125 782 4	17	
	Huambo	170 393 2	5	
3	Luanda	182 132 9	651	242 985 7
	Bengo	185 599	5	
	Cuanza Norte	422 629	18	

*Figures derived from data source for population figures (see Chapter 5)

From Table 6.4. and Figure 6.15. with the exception of Cunene, Huambo and Bengo, it can be seen that each of the selected areas has access to a large population base, demonstrated by population density figures. In selected area 1, which is located in the southern region, individuals in these regions use market activities, occasional labour, sale of livestock, charcoal and firewood, as well as growing of vegetables in the lowlands as a coping strategy in times of food insecurity (FAO, 2006). Extrapolating from this, the proposed selected areas for sugarcane cultivation is a means of agricultural expansion, and thus, would provide an additional source of livelihood for people in this region. The north-central region, in which selected area 2 is located, offers the greatest livelihood options with agriculture and trade dominating (FAO, 2006). Thus, it is more than likely that there is a great deal of individuals with agricultural skills which may prove to be a viable workforce for the selected area 2.

Extrapolating from national statistics, Angola’s HIV/AIDS prevalence rate is only 3.9%, which is low compared to the rest of the southern African region (as outlined in Chapter 4). However, another health risk is affecting the health status of the Angolan population, i.e. cholera. Due to the constrained living and sanitation conditions and inappropriate hygiene practices, the country witnessed an epidemic of cholera from April 2006 (WHO, 2007). The outbreak is thought to have originated in Luanda, which is densely populated (as shown in Table 6.4.), and spread through the country by means of road and sea. Daily incidence rate reached a peak of 950 cases and 3092 related deaths last year. Currently, the outbreak has diminished, however there are still some cases occurring in Luanda, Malanje and Benguela (WHO, 2007).

Considering that the majority of the Angolan labour force is engaged in agriculture and that the country faces extensive unemployment, an expansion of the agricultural sector would undoubtedly create economic opportunities for the population. In retrospect, due to the devastating economic situation which Angolan’s face, it is more than likely that a substantial portion of the population in each of the selected areas can be considered as an available work force.

Various demographic changes take place in rural areas which contributes to labour availability (FAO, 2007). These include migration of individuals to cities for higher wage or the increase in the number of children going to school, thereby increasing education levels. Both these demographic trends will reduce the amount of labour available for farming operations (FAO, 2007). Therefore, more meaningful results could have been obtained if data on demographic changes in Angola were available, as well as if population centres and distances of these centres from the selected areas were known.

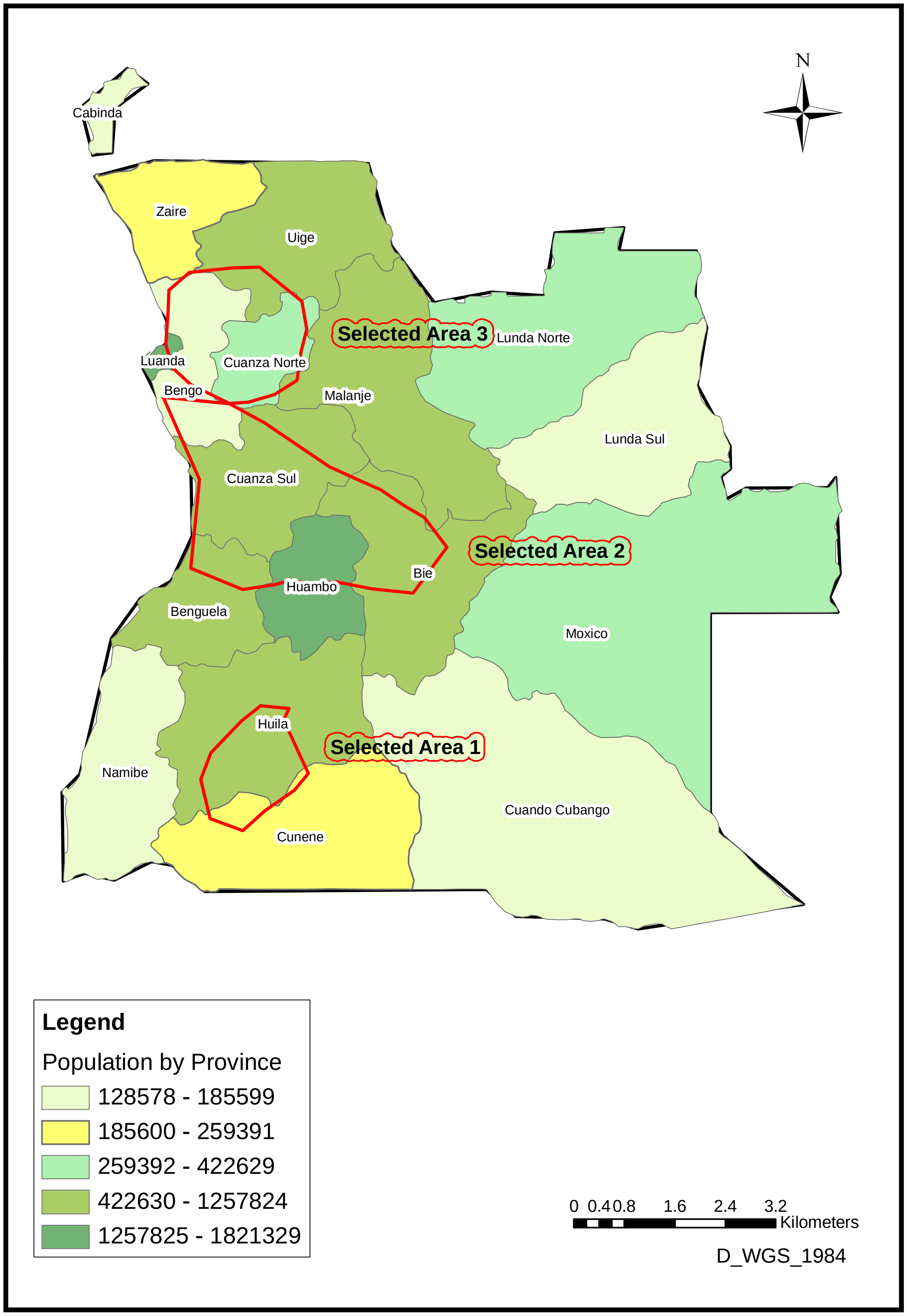

Figure 6.15. Population by province

6.8. Proximity to rivers and percent slope – implications for irrigation

Each of the selected areas were characterised in terms of proximity to rivers and percent slope. Figures 6.16. to 6.18 characterised each of the selected areas in terms of proximity to the nearest river. Figure 6.19. shows the percent slope of the entire study area. From the results, it can be seen that each of the selected areas are covered by a vast network of rivers (Appendix D) which makes irrigation a feasible option. The option of irrigation is especially attractive in selected areas 1 and 2, as they area located in the dryer regions of the country. Specifically, in the four southern most provinces, Huila, Cunene, Namibe and Cuando Cubango, average annual rainfall is below 500-1000mm and therefore irrigation becomes necessary in these provinces. This is particularly relevant for sugarcane cultivation which requires an average annual rainfall supply of 1200-1500mm (Blume, 1985; Tarimo and Takamura, 1998; FAO AGL, 2002). Thus, rainfed agriculture in this region is not a feasible option. Specifically, in the cropping period in years 2005 and 2006, due to poor distribution of rainfall, rainfed agriculture suffered considerable losses in yield in the central region of the country, the northern parts of the Huila province and Cuanza Sul (FAO, 2006).

Loss in crop yields often translates into issues of food security, where a reduction in the amount of crops available decreases food security in the relevant regions. A means by which to avoid such yield losses and improve food security is to move Angolan agriculture from rainfed into dryland farming, thereby increasing dependence on irrigation systems. Furthermore, in a broader socio-economic context, investments in irrigation systems, is seen as means of job creation, market opportunities for small-scale farmers and increased income due to higher attainable crop yields (FAO, 2006).

In terms of irrigation engineering, distance to water source is a factor which influences irrigation economics especially in terms of pumping costs (Dumler and Rogers, 2006). Thus, Figures 6.16. to 6.18 can be used in estimating pumping costs associated with the irrigation system in question as per the stake-holder’s specific circumstances.

Terrain variations were only accessed in terms of percent slope which is represented in Figure 6.19. As previously mentioned in Chapter 5, there appears not to be a definite threshold value at which irrigation becomes constrained. However, the FAO-IIASA (2007) have identified slopes greater than 8% to be severely constrained for non-terraced land with gravity irrigation, and for land with sprinkler irrigation, slopes greater than 16% becomes severely constrained. The results generated in this section serve to assist a stake-holder in the decision-making process of choice of irrigation systems and costs associated. From Figure 6.19.[4] it can be seen that selected area 1 has slopes ranging from 0 - 3.78%, selected area 2 has slopes ranging from 0-17.10% and selected area 3 has slopes ranging from 0-8.44%.

It is acknowledged that in order to generate a better understanding of the terrain variations in the selected area, an accurate assessment of variation in terrain of areas located in close proximity to rivers is required, however, this was beyond the scope of this study. In conjunction with the factors outlined in Chapter 5, this would be a more meaningful contribution to estimating costs involved in establishing a particular irrigation system.

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[4] Slope classes were generated by the natural break define method in ArcMap.

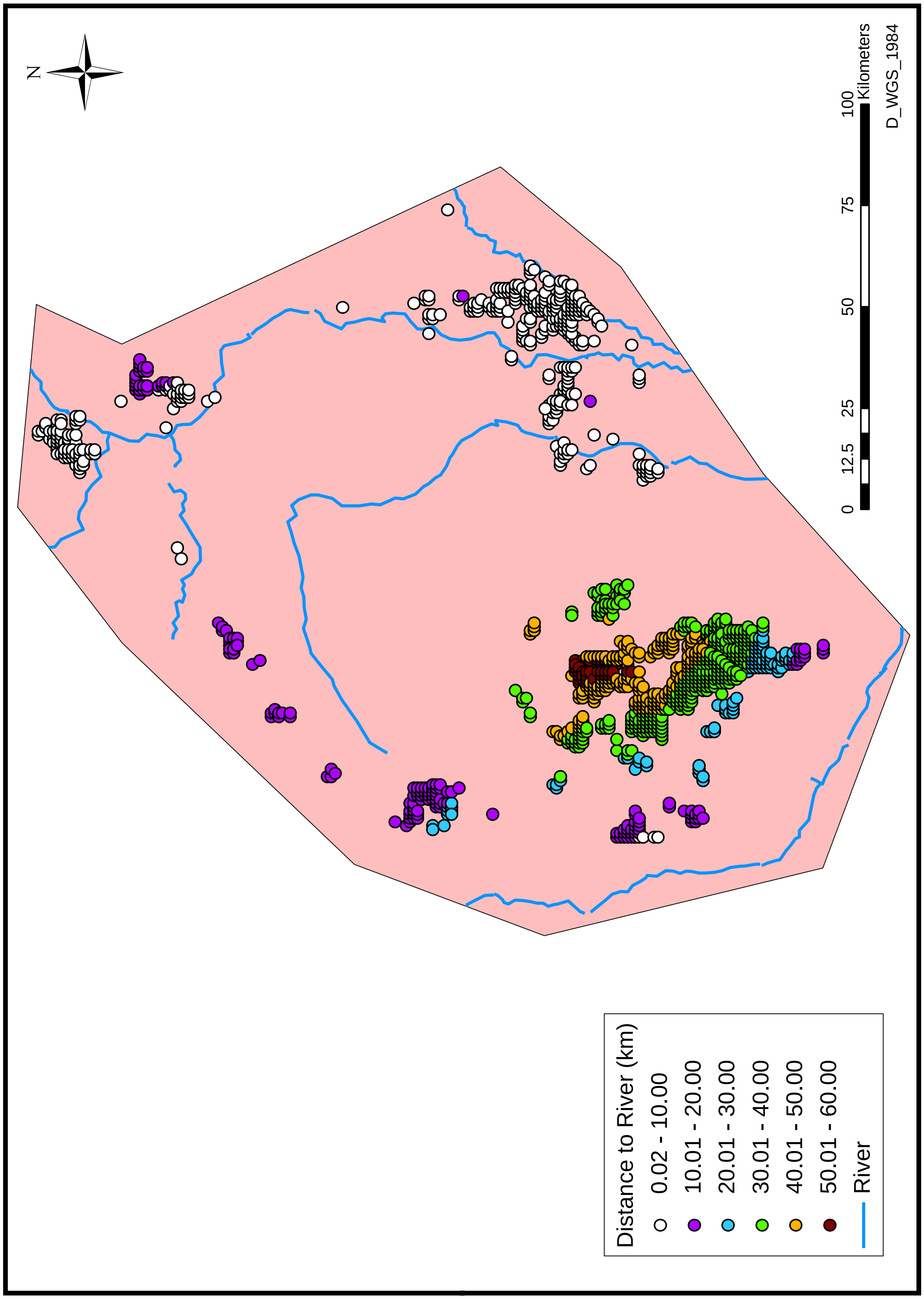

Figure 6.16. Proximity to rivers in Selected Area 1

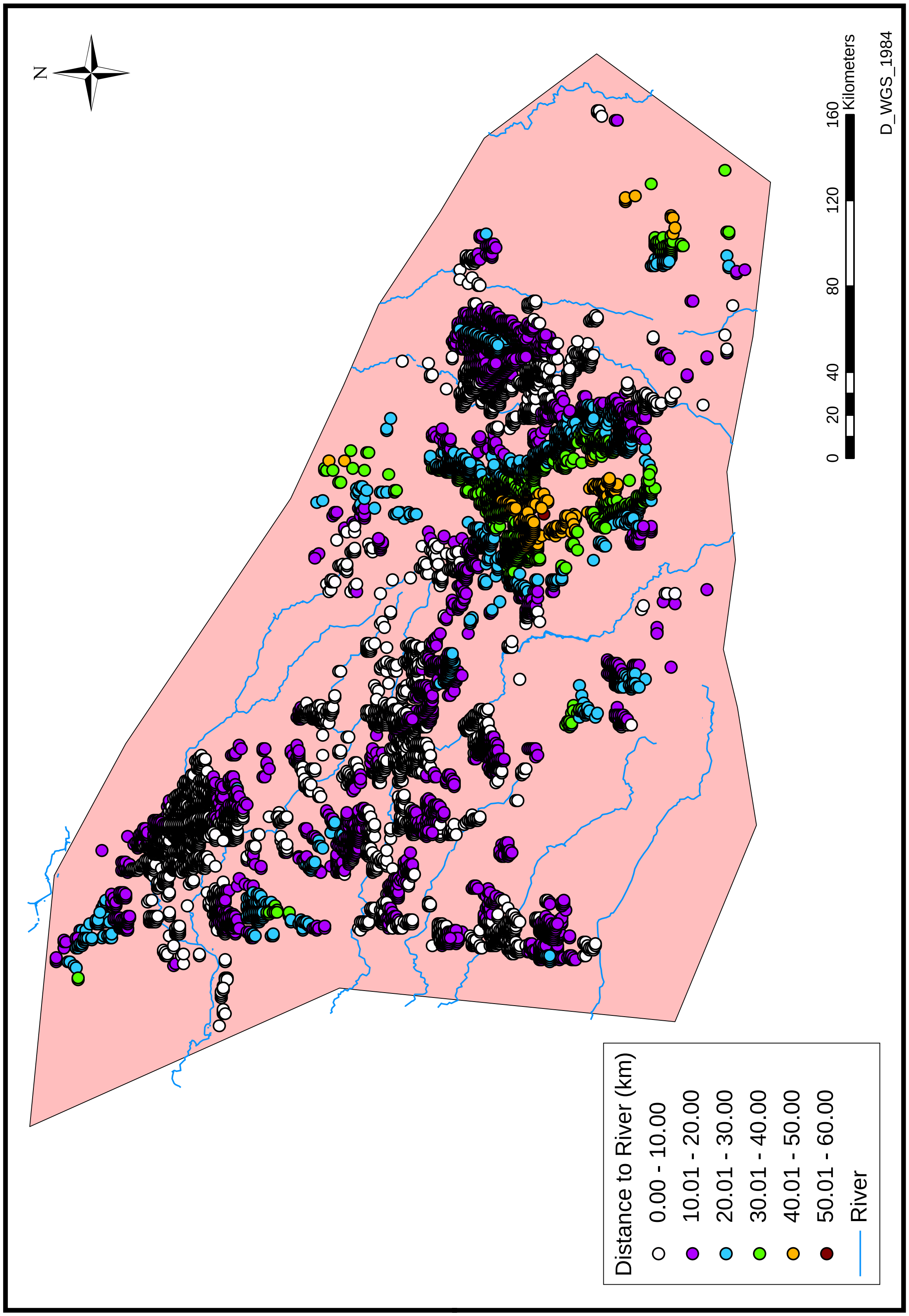

Figure 6.17. Proximity to rivers in Selected Area 2

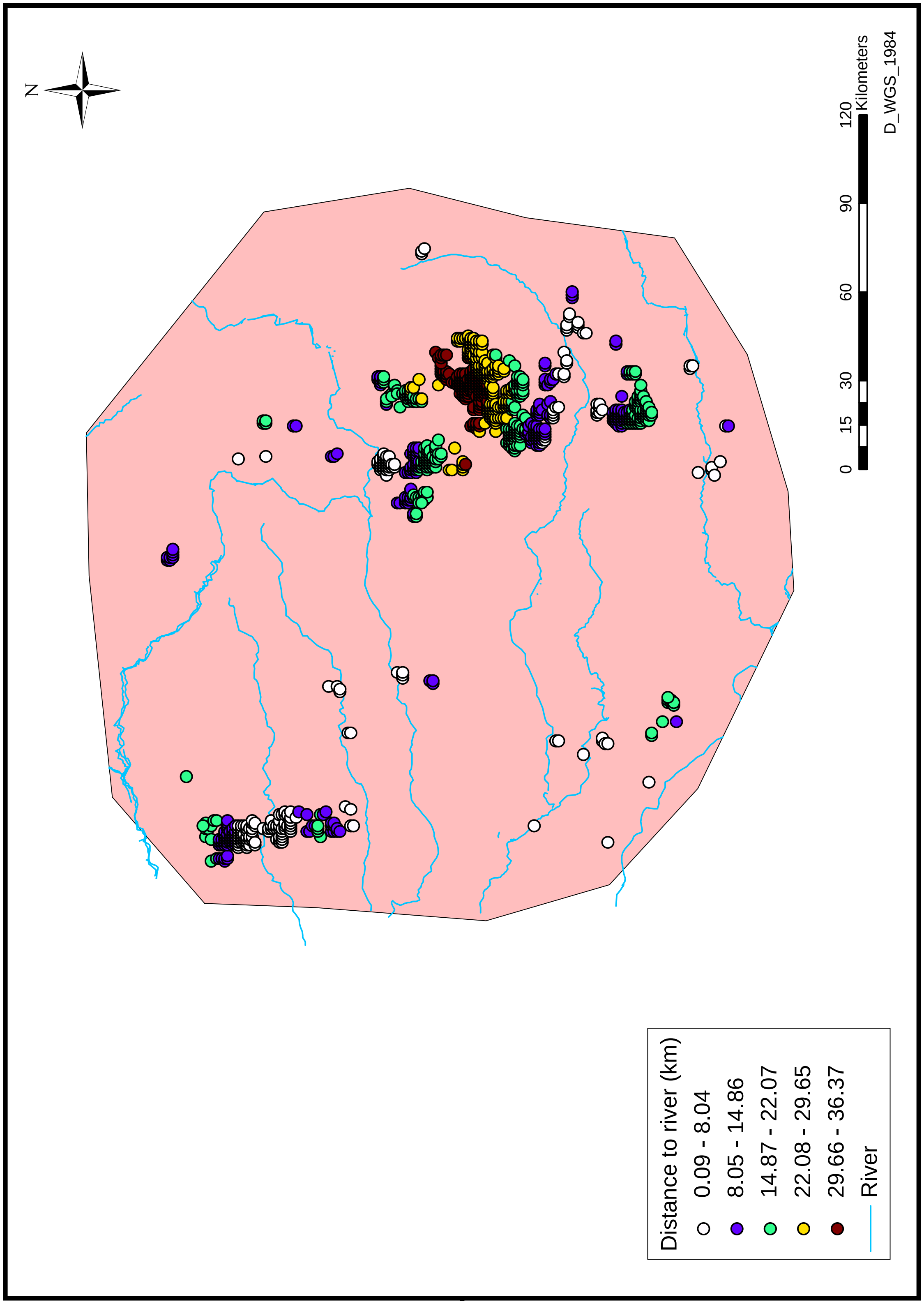

Figure 6.18. Proximity to rivers in Selected Area 3

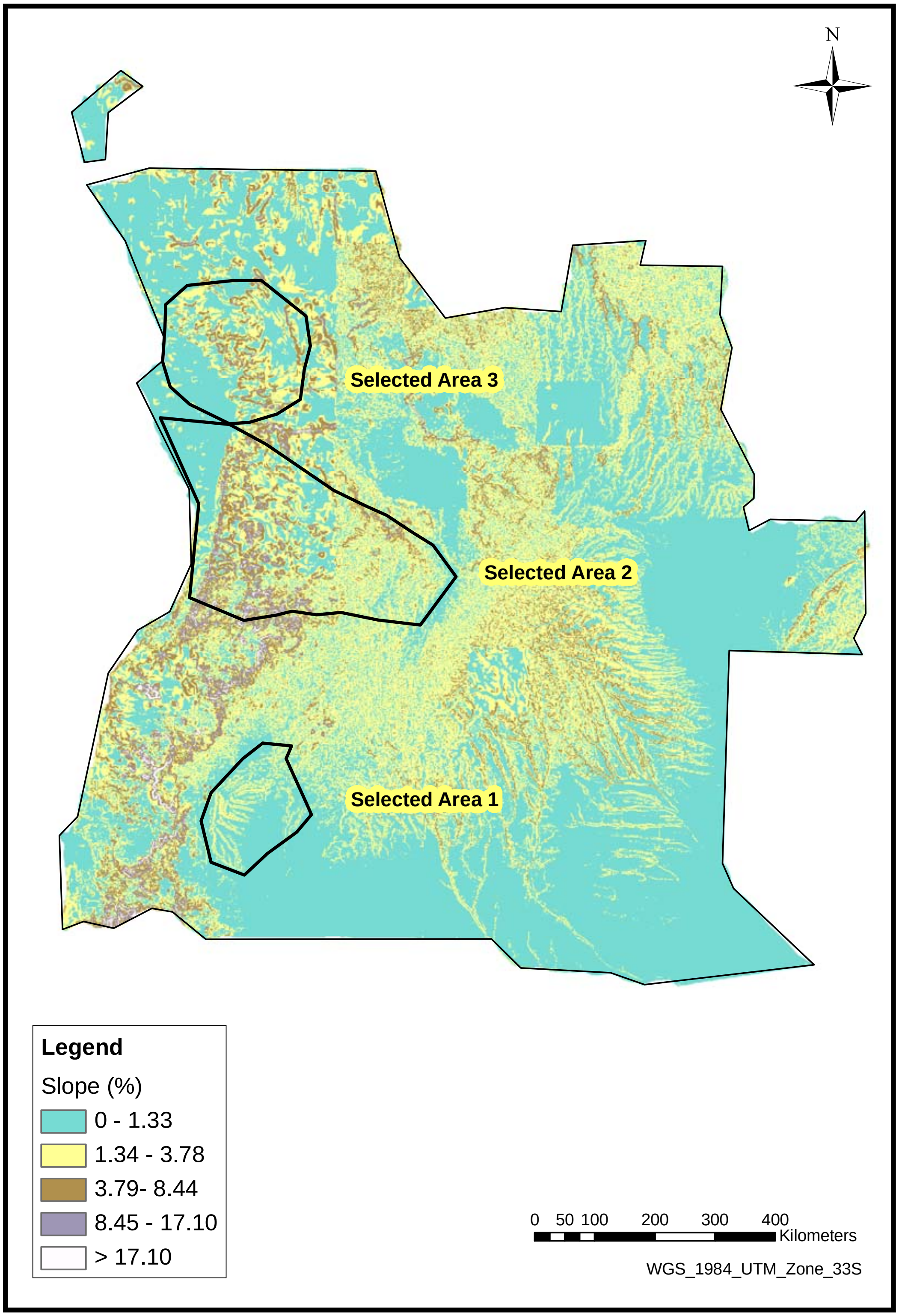

Figure 6.19. Terrain variation in the study area as per percent slope

6.9. Conclusion

This chapter has presented and discussed the findings of the analyses performed. It is clear that there exists great potential for establishing sugarcane farms due to the large areas identified. Furthermore, Angola’s unexploited irrigation potential and vast river network makes irrigated agriculture an attractive option. The following chapter represents the conclusion of the project as a whole and includes recommendations emanating from the study.

Chapter 7

Conclusion and Recommendations

The previous chapter presented and discussed the results of the land suitability assessment for sugarcane cultivation in Angola. This chapter serves to provide a conclusion of the project as a whole, in terms of key findings, objectives met and recommendations.

7.1. Key findings

In the study, all objectives as outlined in Chapter 1 have been met. Results indicate that Angola has enormous potential for bioenergy production. Specifically, following several filtering steps, the total land area that is suitable for sugarcane cultivation in Angola is 10 614 km^2. As mentioned in Chapter 5, due to the lack of reliable data, it is uncertain as to where existing sugarcane farms are located. However, it is known that currently the area under crops is 4 million hectares, of which 9 500 hectares (95 km^2) were under sugarcane cultivation in 2004 (Makenete, 2007). It is likely that these areas were filtered out during filtering of areas which overlapped with the cropland land cover class. Thus, from the results obtained, an additional 10 614 km^2 of land has been identified which could potentially be placed under sugarcane cultivation. Since, commercial sugarcane farming requires areas of 10 000 hectares (100 km^2) and greater, the identified suitable areas would provide at minimum 106 such ventures.

Even though, the aim of the project was not to identify specific sites at which sugarcane farms could be adopted, results from this study have served to narrow down Angola’s 57.6 million hectares of agricultural land to areas which would be most suitable for sugarcane cultivation. It is acknowledged that the accuracy of these suitable areas has the potential to be greatly increased, as outlined in Chapter 5.

In addition to identifying potentially suitable areas for sugarcane cultivation, a broad assessment of the transport infrastructure surrounding each area has been made. This included road and rail transport which is essential to delivering goods and farmer’s supplies into the agricultural area as well as delivering agricultural produce to the manufacturing phase (mill or distilleries). Interestingly, the identified selected areas appear to be large enough to house individual mills in close vicinity to their agricultural phase. For example, drawing from his experience in Brazil, Bezuidenhout (2007, *pers. comm.*) has suggested that it is possible for four mills to be built in selected area 1. Specifically, for sugarcane growing under irrigation, yield on average is 100 tons/hectare, with each mill have the processing capacity of 3 million tons. As selected area 1 covers an area of 1 258 km^2, four[5] mills would be required to process the agricultural produce from this area. As such, processing capacity at each of the selected areas appears encouraging as each of the selected areas has the potential to house a minimum of three mills.

By further extrapolating from productivity figures in Brazil, a 2004 productivity index estimates that 135 litres of ethanol is produced per ton of sugarcane (Martines-Filho *et al.*, 2006). Since 10 614 km^2 of land was identified in this study as being suitable for sugarcane, this land area has the potential to produce 106 million tons of sugarcane and an astounding 14 329 million litres of ethanol (Table 7.1.). This astounding productivity potential could place Angola as the world's third largest producer of ethanol! Comparing this figure to world ethanol production in 2005, where the U.S. and Brazil produced 16 214 million and 16 017 million litres of ethanol, respectively, it indeed affirms the suggestion made by Van den Berg and Rademakers (2007) that Angola is set to be the world's next biofuel 'superpower'.

Table 7.1. Estimated bioethanol productivity potential for Angola, extrapolated from Brazilian productivity figures

Land area (km^2)*	Tons of sugarcane	Litres of bioethanol
0.01	100	13 500
10 614	106 140 000	14 329 million

*1 km^2 is equivalent to 100 hectares

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[5] This value was arrived at by taking the suitable land area of selected area 1 and multiplying it by the average yield. This gave a value of yield in tons/hectare which was divided by 3 million. The resulting value was taken as a general indication of the number of mills it would take to process produce from this area, as it is beyond the scope of the study to suggest precise locations for mills.

Furthermore, calculating proximity to rivers in each of the selected areas revealed a vast network of rivers in each of the areas, demonstrating the high irrigation potential that exists in the country. In conjunction with slope (%) calculations, these figures can prove useful to a stake-holder's decision-making process as per options in irrigation systems and economics involved. In Angola, investments in irrigation systems would ensure long-term development. Such technological advancements are considered key in the development of Angola's agricultural sector, which has associated benefits for both small- and large-scale farmers. These advantages and benefits have been discussed in detail in Chapter 4.

It is imperative to remember that the areas identified were for the cultivation of sugarcane for bioenergy purposes. Thus, in this light sugarcane is considered as a bioenergy crop with the capacity to produce several bioenergy products which includes bioethanol, such that its cultivation is not solely for the production of sugar. These areas therefore have an added advantage in terms of bioenergy products which could be a means of uplifting social welfare, and the creation of rural livelihoods. These suitable areas can help turn marginalised farmers into commercial producers (Makenete, 2007). Furthermore, such bioenergy crop plantations can be rotated with higher-value cash crops. In the case of sugarcane, there are further opportunities involved for a producer who is capable for making both sugar and bioethanol (as discussed in Chapter 3).

Specifically, the Government of Angola sees clean, renewable energy as a promising endeavor to address the basic development needs of low-income populations. Angola's Minister of Energy has outlined that improving access to cleaner forms of energy, becomes critical in freeing the poor, especially women from subsistence farming (Commission on Sustainable Development, 2001). There is undoubtedly also a need for energy services in Angola such as electric power, as only 15% of the Angolan population have access to electric power (www.esri-africa.com). As outlined in Chapter 3, bagasse-cogenerated electricity affords the sugarcane factory to be sufficient in meeting its energy requirements, and in a case in which the factory is being operated efficiently, excess bagasse may be available. This can be used to generate electricity which could be sold to the national grid. This can prove to be a great endeavor in meeting Angola's energy needs, not to mention the additional energy and environmental benefits associated with other sugarcane bioenergy products, such as household gel-fuel.

7.2. Recommendations

Several recommendations have emanated from this project and these are listed below**:**

1. The potential value of Google Earth® in verifying whether identified areas are uninhabited has been demonstrated in this study. It is recommended that this application be used to verify availability of land in future land suitability assessments.

2. The inclusion of existing sugarcane farms in the study is crucial in rendering the suitability assessment more reliable and accurate. As shown by Baijnath (2005), the MIOMBO SLCR pixels have included some of the areas which are under sugarcane cultivation. Adopting such an approach would ensure that areas identified as suitable for sugarcane cultivation would not include land currently under sugarcane cultivation.

3. It is suggested that, prior to establishing sugarcane farms at the suggested areas, results from this study should be supplemented with an economic evaluation, taking into account detailed costs and benefits associated with the development project. Assessments of suggested areas in terms of the surrounding social, economic and physical context as well as the availability of local and export markets, costs and benefits of input, as well assessments including land tenure, should also be made (FAO, 1976). Specifically, surveys at the semi-detailed or intermediate level would prove more meaningful by incorporating more specific aims and a feasibility study of the development project (FAO, 1976).

4. Due to the scope of this study, the potential for irrigated agriculture was broadly addressed by assessing distance to water source and slope. Results have shown that Angola has an unexploited irrigation potential and thus, it is recommended that in order to fully realise this potential, in addition to recommendation 3, a more detailed

land evaluation mainly focussing on irrigated agriculture be conducted. An evaluation of this nature may follow the FAO’s (1985) document *Guidelines: Land evaluation for irrigated agriculture*. In addition to the results obtained in this study, such an evaluation may further prove beneficial to a land developer in terms of deciding the best irrigation method for a particular land area, as well as costs of inputs and outputs and relating these to the surrounding environmental, social and political context (FAO, 1985).

5. Laws and legislation pertaining to land use, land tenure and use of water for irrigation have not been addressed in this study. An understanding of the laws pertaining to these would prove beneficial in estimating the feasibility and laws regulating the establishment of sugarcane farms at the suggested areas.

6. It is further recommended that in order to facilitate best farming practices and highest yield attainable, study trials should be conducted as to which sugarcane variety would be successful in each of the suggested areas.

7. Results from this study showed that Angola has enormous bioenergy productivity potential, and to assist in fully realising this potential, it is urged that an international cooperation be established between Angola and the North. This would bring scientific, technical and agronomic expertise into the country for bioethanol production. A cooperation should also be established with Brazil, which is the world’s leading producer of ethanol from sugarcane. As suggested by Makenete (2007) a trilateral cooperation between Africa, the European Union (EU) and Brazil could prove highly beneficial for all three stake-holders. Specifically, the EU could bring financial and technical resources and Brazil could bring scientific and technical expertise for bioethanol production. Africa on the other hand would be the biofuel producer which could lift marginalised farmers out of poverty and can export its produce to the EU.

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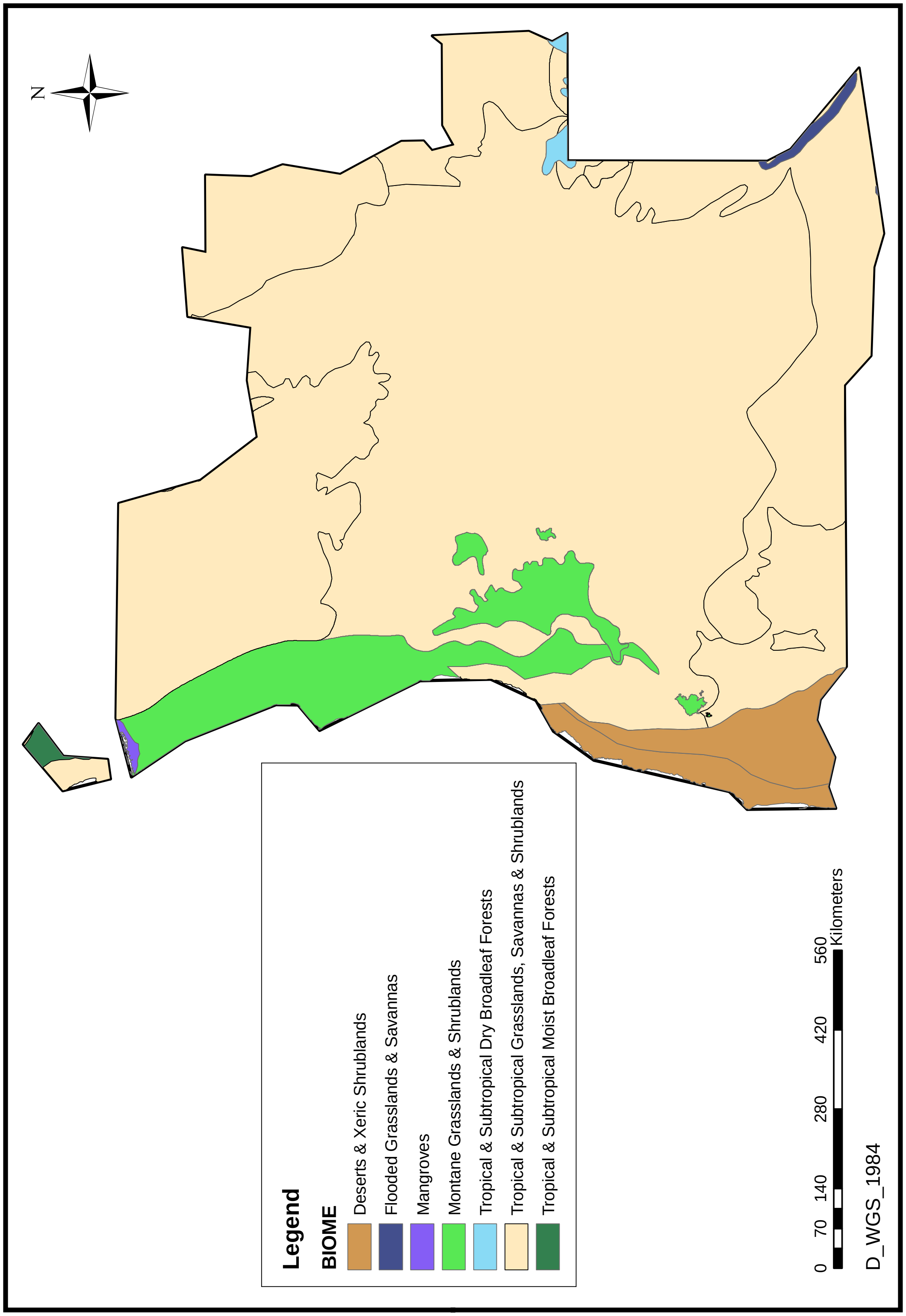
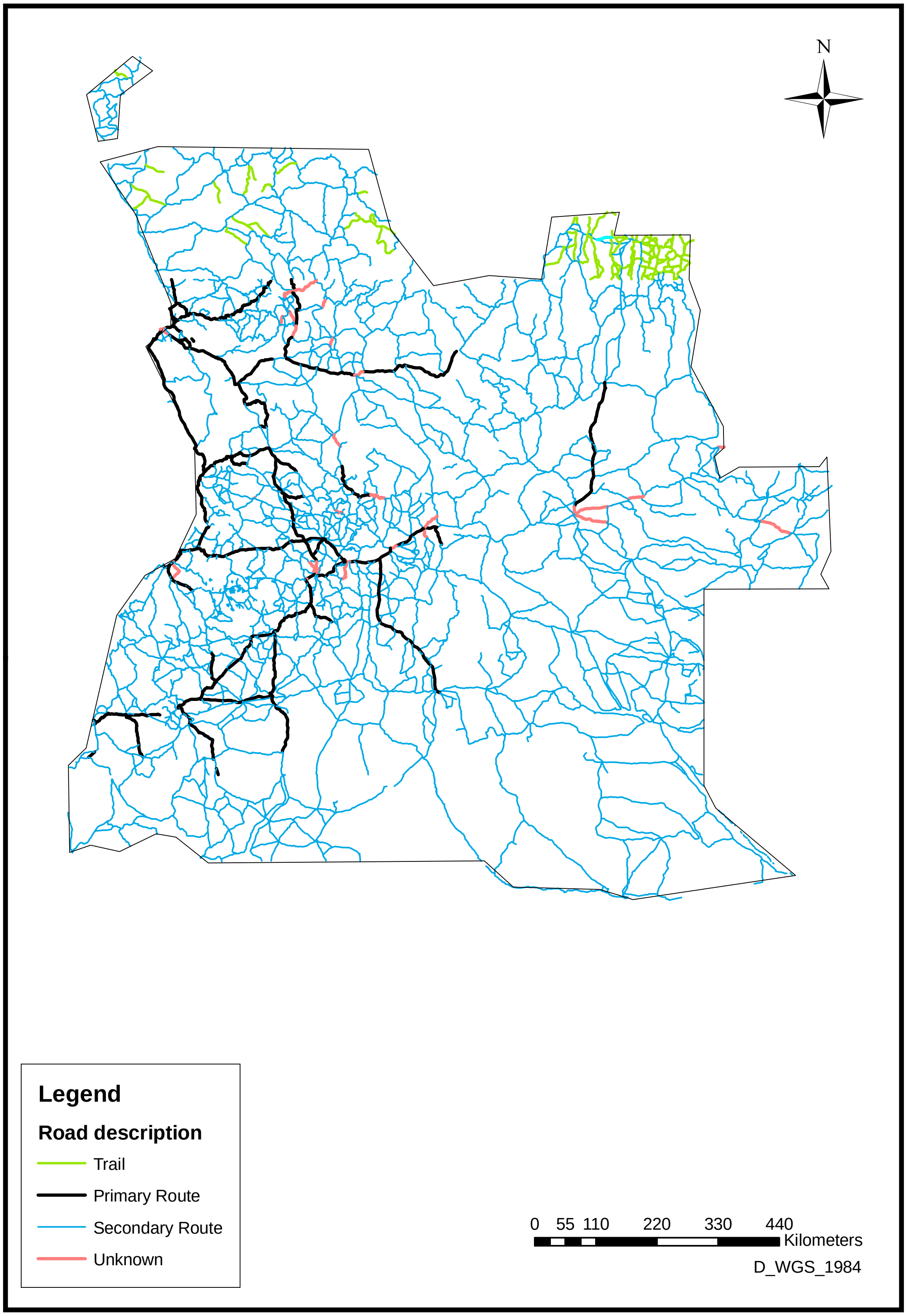
APPENDIX A



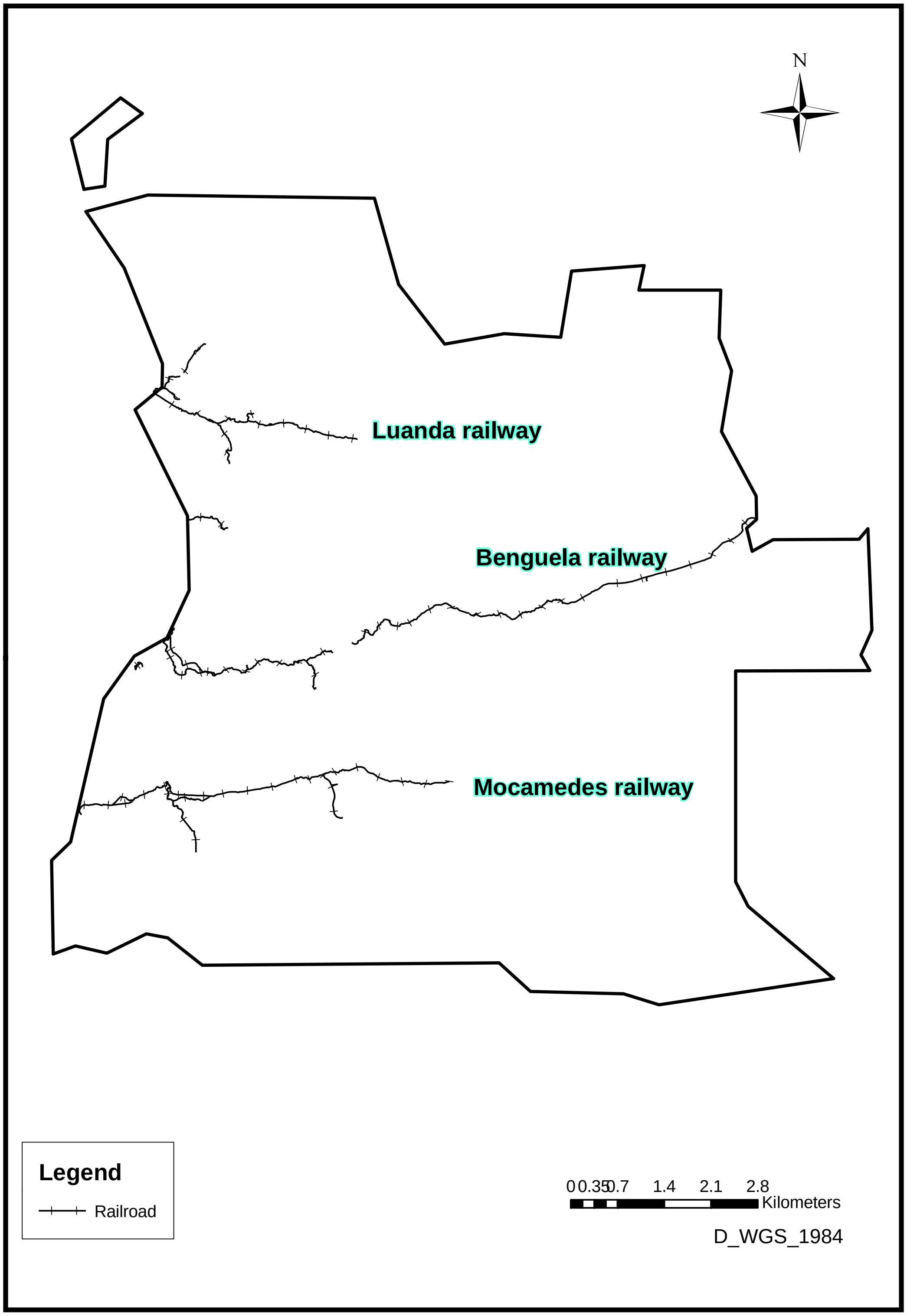
Biomes of Angola; *Source: ESRI® Data & Maps 2006*

APPENDIX B



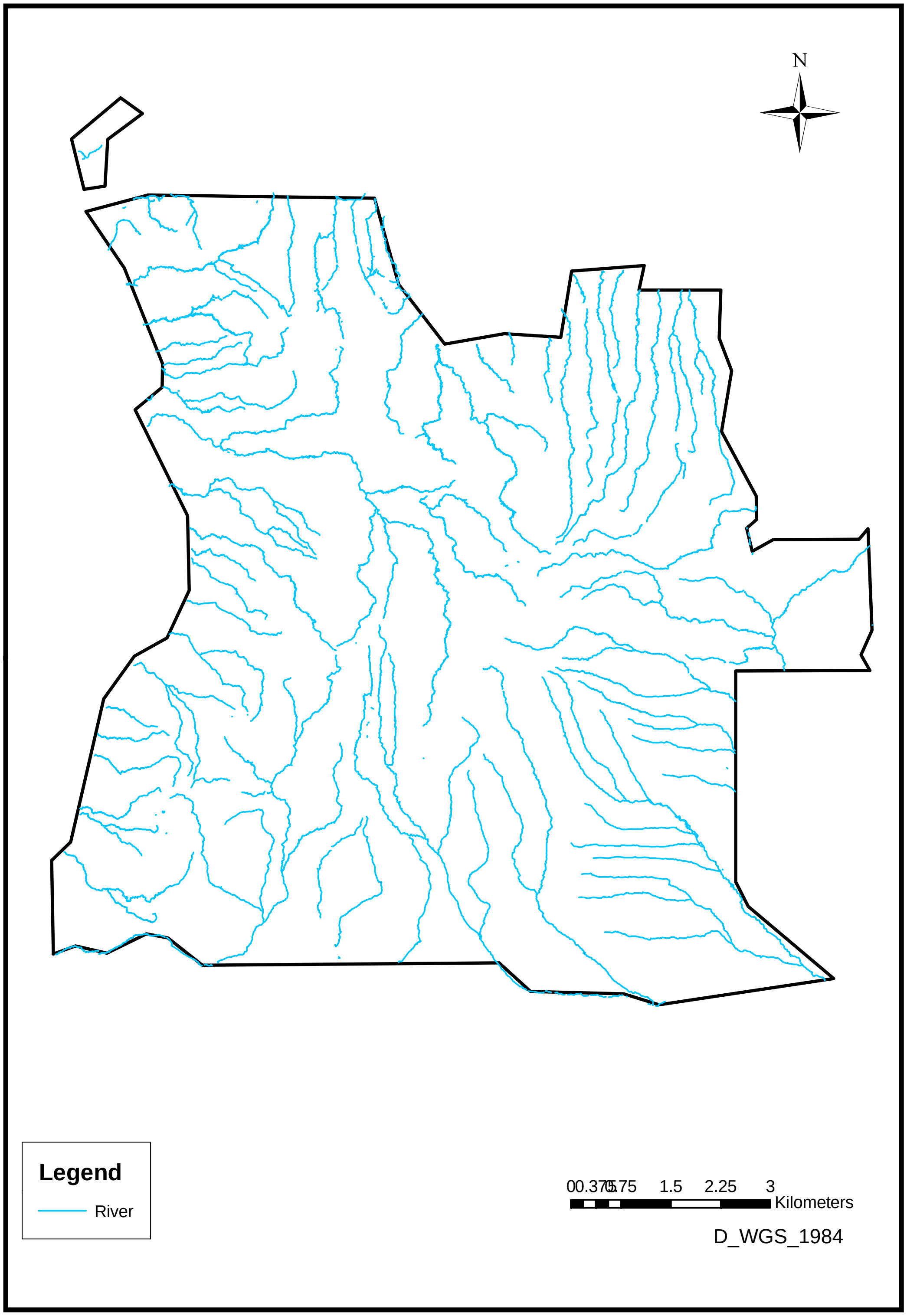
Distribution of Roads in Angola

APPENDIX C



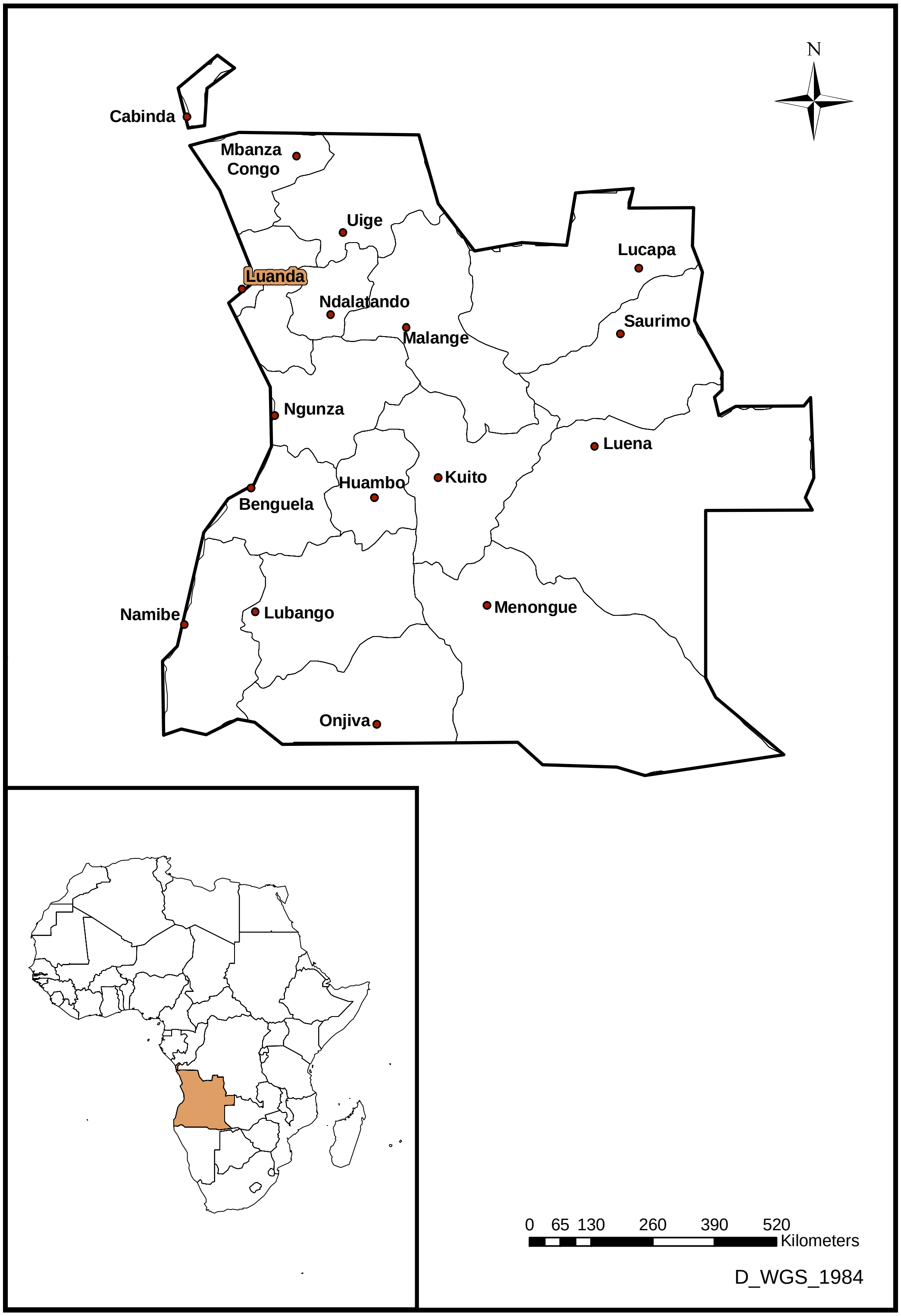
Railroads in Angola

APPENDIX D



Permanent Rivers in Angola

APPENDIX E



Cities in Angola; *Source: ESRI® Data & Maps 2006*